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WATERFLOOD BEHAVIOR OF VISCOUS OILS

by

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ABSTRACT

Waterflooding tests were carried out on unconsolidated sands packed in stainless steel coreholders to investigate the relationship between oil recovery and a scaling number which is the ratio of viscous to capillary forces. The cores were approximately 4 ft. (1.34 m) long and were of two diameters; 4 in. (10.16 cm) and 2 in. (5.08 cm). The permeability of the cores varied between 8 and 16 darcies and the porosity was constant at about 36%. A completely new sandpack was used for each waterflood run performed.

The main parameter studied was the rate of injection which was varied between 2.5 and 800 cc/hr. Two oils were used; the first a Dow Corning 200 fluid (500 c.s.) and the second a Wainwright crude oil (1080 c.s.). All runs were performed in the presence of an initial water saturation in the core.

Both oils exhibited rate sensitive breakthrough recoveries. With the Dow Corning fluid the recovery showed a decrease in breakthrough recovery as injection rate was increased whereas with the Wainwright crude oil breakthrough recovery increased with increasing injection rate. Completely different mechanisms were postulated to explain the seemingly contradictory results.

ABSTRACT

Waterflooding tests were carried out on unconsolidated sands packed in stainless steel coreholders to investigate the relationship between oil recovery and a scaling factor which is the ratio of viscous to capillary forces. The cores were approximately 4 ft. (1.14 m) long and were of two diameters: 4 in. (10.16 cm) and 2 in. (5.08 cm). The permeability of the cores ranged between 5 and 10 darcies and the porosity was constant at about 36%. A completely new sandpack was used for each waterflood run performed.

The main parameter studied was the rate of injection which was varied between 2.5 and 250 cc/hr. Two oils were used; the first a Dow Corning 200 Fluid (100 c.p.), and the second a Wainwright crude oil (1450 c.p.). All runs were performed in the presence of an initial water saturation in the core.

Both oils exhibited rate sensitive breakthrough recoveries. With the Dow Corning Fluid the recovery showed a decrease in breakthrough recovery as injection rate was increased whereas with the Wainwright crude oil breakthrough recovery increased with increased injection rate. Completely different mechanisms were postulated to explain the seemingly contradictory results.

A region of non-Darcy flow was found to exist at high displacement rates but could not be used to explain the trend in observed breakthrough recoveries. Fingering in the core at the flood front would explain the decrease in breakthrough recovery with increasing rate of injection observed in the tests with Dow Corning fluid. For the Wainwright crude oil, water-in-oil emulsions were formed in-situ and this emulsification provided a five-fold increase in breakthrough recovery from very low rates to very high rates.

Mixing associated with increasing rates produced the emulsions which resulted in the increase in recovery; however, these rates were very much higher than field conditions would allow.

Emulsion stability appeared to correlate with the amount of recovery and this stability appears to be related to either the absolute permeability or to the amount of initial water present in the core.

ACKNOWLEDGEMENT

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I. INTRODUCTION

Waterflooding is the oldest of the enhanced recovery methods having been discovered by accident in 1865. It is still the most important of the secondary recovery methods in terms of oil produced and in the Province of Alberta over 80% of the oil recovered by enhanced recovery methods is by waterflood. Because of its popularity a colossal amount of literature is available on the subject. Many contradictions exist in this literature.

One of the most controversial parameters in a waterflood design is the rate of injection. Many researchers [3,15,18,20] report increasing breakthrough recovery with increasing rate, while others report stabilized recovery[8,16] and others[5,9,10,13,23] report decreasing recoveries with increasing rate of injection. The phenomenon of viscous fingering has been investigated by many researchers[4,5,7,10,13,21,23], including some from the Department of Mineral Engineering at the University of Alberta. Low viscosity to medium viscosity oils have been used in these studies. As production of heavy crude oil becomes more economical high viscosity crudes should be investigated with particular reference to waterflood behavior. Since the economics of waterflooding has been proven in many conventional light oil reservoirs it may well be applied with <u>some</u>

success to heavier oil reservoirs.

The aim of this work was to examine the behavior of viscous oil (i.e. Wainwright crude oil - 1000 c.s.). Also an attempt was made to obtain laboratory data free of changing initial conditions such as rising initial water saturations from run to run.

II. BACKGROUND

Engelberts and Klinkenberg[10] coined the term "viscous fingering" from observations of their experimental work in 1951. They visually observed gross water channeling at high water injection rates in water-wet systems leading to severe decreases in breakthrough recoveries. The fingers in their system were attributed to instabilities developing in the transition zone separating the injection water from the undisplaced oil. They were able to correlate their results by the use of the scaling group "I" which is a ratio of viscous to capillary forces in the core.

$$I = \frac{LV\mu_w}{\sigma\sqrt{K}} \qquad (1)$$

I = ratio of viscous to capillary forces (dimensionless)

L = length of sand pack (cm)

μ_w = viscosity of water in system (cp)

σ = interfacial tension (dynes/cm)

K = absolute permeability of sand pack (cm^2)

V = velocity of the front (cm/s)

Rapoport and Leas[18] and Kyte and Rapoport[14] show that the scaling group "I" controls the length of the capillary transition zone in the system. As the value of the scaling group decreases this transition zone increases. The

transition zone referred to here is the frontal region between the initial water saturation and the flood front saturation (Sw_f). As the scaling group increases the flood becomes stabilized (i.e. the capillary transition zone does not change with time) and the recovery becomes insensitive to further rate increases. At highly unfavourable viscosity ratios they did observe a decrease in recovery as rate was increased but they attributed this to an inlet end effect.

Geertsma et al.[12] examined all the variables relevant to waterflooding and developed a more general dimensionless scaling group which they called the Leverett number (L_t). L_t is the ratio of capillary to viscous forces in the core.

$$L_t = \frac{\sigma \cos \theta \sqrt{K\phi}}{\mu_w VL} \qquad (2)$$

where:

θ = wetting angle of fluid interface (dimensionless)

ϕ = porosity (dimensionless)

The scaling group "I" is a simplification of this group and may be used if the wettability conditions and porosity are held constant.

In 1957 van Meurs and van der Poel[21], using an idealized representation of viscous fingers, developed a mathematical description of waterflooding involving viscous

fingering. Wiborg[23] presented this theory in detail in his thesis in an attempt to predict the results of his experimental studies.

Chouke et al.[4] in 1958 derived a theoretical description for viscous fingering by formulating an equation for the peak to peak separation of the fingers.

$$\lambda_m = C \left[\frac{\sigma \ K}{V(\mu_o - \mu_w)} \right]^{\frac{1}{2}} \tag{3}$$

λ_m = the average wave length (peak to peak)(cm)

K = absolute permeability (cm^2)

V = superficial velocity (cm/sec)

σ = interfacial tension (dynes/cm)

μ_o, μ_w = oil and water viscosity (poise)

C = CHOUKE constant (dimensionless)
(different for each system)

The constant C was introduced to allow for the fact that the effective interfacial tension in a porous medium containing connate water will be somewhat greater than that measured in the laboratory on a planar surface. They assumed that this effective interfacial tension would be directly proportional to the measured interfacial tension, hence the constant C.

They also related this average wavelength to a critical wavelength which is the smallest wavelength possible at the onset of fingering.

$$\lambda_{cr} = \lambda_m/\sqrt{3} \tag{4}$$

where: λ_{cr} = critical wavelength

At the onset of fingering the critical wavelength must equal the model width, D, or $\lambda_{cr}/D = 1$. This critical wavelength for the system adds a third requirement for instability because capillary forces have been considered in Chouke's analysis. The three conditions necessary for instability are:

1. A velocity greater than some critical velocity defined for the system.
2. An adverse mobility ratio.
3. The system must contain modes of wavelengths greater than the critical wavelength of the system.

By using the fact that at the onset of fingering the critical wavelength must be the same size as the model width an expression for C for the particular system may be obtained.

$$C = \left[\frac{3\ V(\mu_o - \mu_w)\ D^2}{\sigma\ K}\right]^{\frac{1}{2}} \tag{5}$$

By solving Equation (1) for σ and substituting into Equation (5), we obtain C in terms of the scaling group "I".

$$C = \left[\frac{3\ I\ \frac{\mu_o}{\mu_w} - 1\ \ D^2}{L\sqrt{K}} \right]^{\frac{1}{2}} \tag{6}$$

Chouke[4] also states that additional scaling is needed if viscous fingering is present in the system and suggests that the group $[\lambda_m/D]^2$ be the same in the model and the prototype. However, he identifies three cases found in laboratory floods and states that for two of the cases the additional scaling rule may be dropped.

Case 1) $\lambda_m/D << 1$ here a large number of fingers are present and Chouke suggests that production is independent of rate.

Case 2) $\lambda_m/D >> 1$ here the peak to peak distance is larger than the width of the model and the behavior is then like that of a stable displacement.

Case 3) $\lambda_m/D \simeq 1$ here the finger spacing is approximately equal to the canal width and the production behavior could be affected. When this condition is met the additional scaling parameter $[\lambda_m/D]^2$ is needed and should be the same in the model and the prototype.

Kloepfer[13] in 1975, observed the effect of rate on the displacement efficiency at favourable and unfavourable

viscosity ratios. He found no decrease in breakthrough recovery as the rate was increased when the viscosity of the displacing phase was greater than that of the displaced phase. He did notice a decrease in recovery at unfavourable viscosity ratios as the rate of injection was increased.

There were problems in interpreting the data for the viscosity ratio (μ_o/μ_w) of 6.4 since the wettability of the sand pack appeared to be changing as the flood series progressed. To prepare the core for a new flood a displacement, with oil, was conducted until initial conditions were established without cleaning between the runs. According to Kloepfer[13] this substantial period of time from the start to the finish of a series may have allowed polar type components in the crude oil to adsorb on the sand surface. A decrease in breakthrough recovery was noted in the runs that were considered to be water-wet and no decrease was noted in the runs considered to be neutral or oil-wet.

Wiborg[23], in 1976, studied the effect of injection rate at more adverse viscosity ratios. He used three oils with viscosities varying from 14 to 110 centipoise. The results indicated a decrease in breakthrough recovery as the rate of injection was increased for all three oils. Wiborg[23] attributed this decrease in recovery to fingering within the core. With one of his oils the recovery increased again as the rate of injection was increased to

very high values. For this oil Wiborg[23] observed water-in oil emulsions being produced from the core at these very high rates.

A major problem encountered by Wiborg[23] was a continually rising initial water saturation. His initial water saturations varied from 10-15% at the start to 25-30% at the end of his series of runs for two of his oils. For his third oil, a Dow Corning fluid, the initial water saturation was relatively constant from run to run. Wiborg[23] noted that when resaturating with this Dow Corning fluid he would have to stop injection when the initial water saturation was in the proper range to avoid a decreasing initial water saturation from run to run. This might be explained by a change in wetting characteristics within the core. The core pack was changing from water-wet to oil-wet. Oil-wet systems typically exhibit lower connate water saturations than similar systems that are water-wet.

III. EXPERIMENTAL EQUIPMENT AND MATERIALS

A. EQUIPMENT

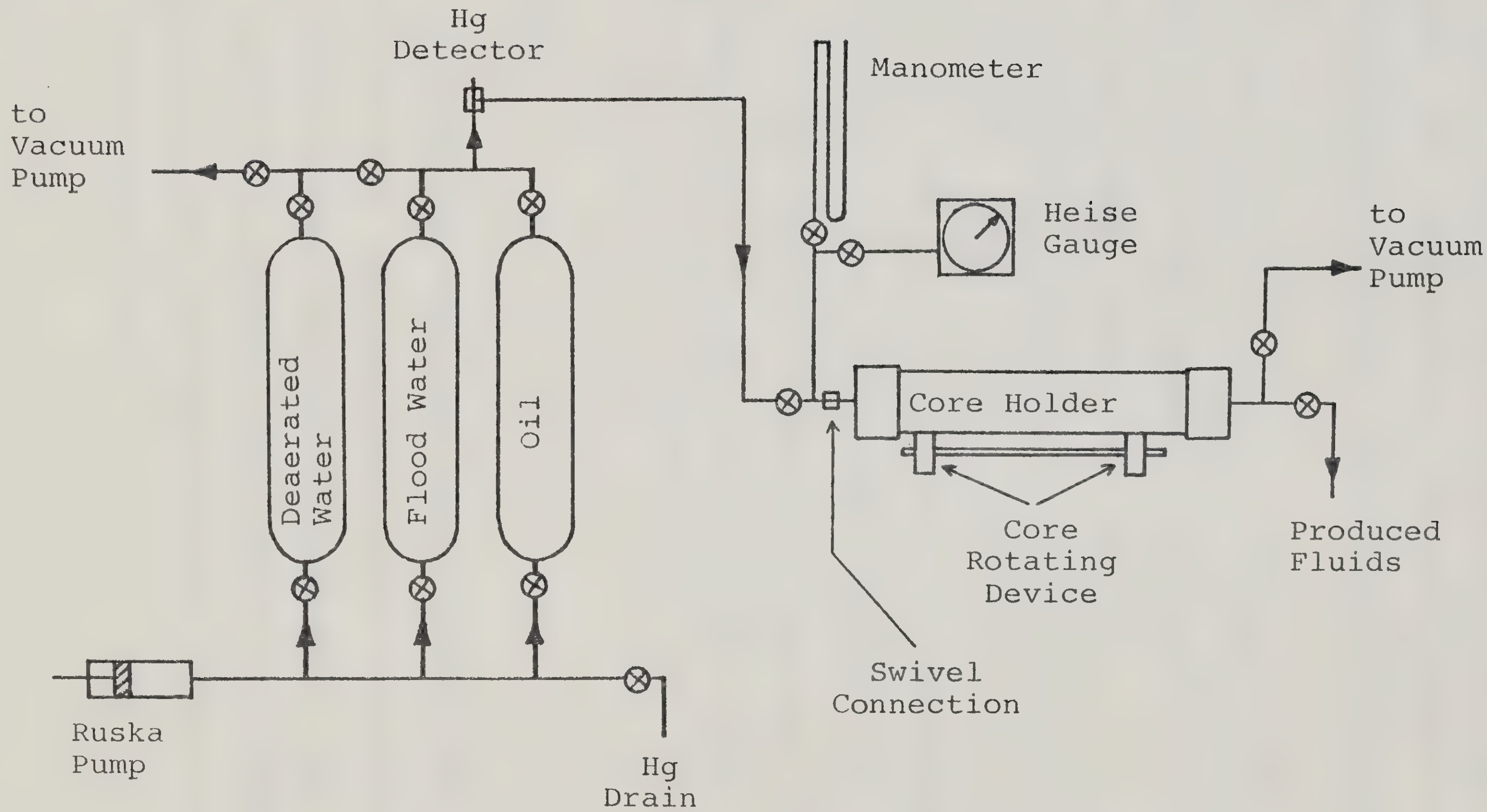
The coreholders used for this set of displacement tests were made of stainless steel and of the same design as those used by Wiborg[23]. The majority of runs were performed using the 2 inch inside diameter coreholder and considerably fewer runs were made using a 4 inch inside diameter coreholder. Both coreholders yielded sand packs of approximately 107 cm in length depending on the amount of sand added in the packing process. The endcaps and coreholders are described in detail by Wiborg[23] and the design specifications are also contained in his thesis.

Whereas Wiborg[23] used only a 200 mesh screen to prevent the sand from plugging the radial and concentric grooves in the endcap face, this set of experiments was performed using a 400 mesh screen clamped to the endcap and a double-200 mesh screen was also placed between the 400 mesh screen and the sand. It was thought that this would help to allow the injection water to reach the sand face more uniformly and make the physical inlet end effect very small. The double-200 mesh screen acts as an additional spreader plate to aid the grooves in the injection head face.

A schematic diagram of the displacement equipment is shown in Figure 1. Mercury was injected into the fluid bombs by a constant rate Ruska pump which displaced fluid out of the bomb and into the core. This procedure was followed so that the pump did not have to be cleaned with every change from oil to water or water to oil; the bombs could simply be drained and refilled. Mercury was the only substance in contact with the pump. All fluid lines were made of high pressure stainless steel tubing.

When a packed core was ready to be waterflooded it was placed on an automatic rotating device which in the case of the 2 inch diameter cores rotated the core one revolution per hour. The purpose of the rotator was to eliminate the effect of gravity in the core and try and prevent a water tongue from forming along the bottom of the coreholder. This rotating of the core necessitated the introduction of the high pressure swivel head at the upstream end of the core.

The produced fluids simply dropped from the downstream end of the core into 50 ml graduated centrifuge tubes. The centrifuge tubes were in a circular holder which held 24 tubes and this holder was connected to a motor and a timing device made it possible to select a time interval for each tube. When the timer was used the collector would automatically switch to the next tube when the set time had expired. For example, if a time of 5



FIQURE 1: SCHEMATIC OF DISPLACEMENT EQUIPMENT

minutes was chosen, an empty tube would be rotated into place under the end of the core every 5 minutes. A small centrifuge was used to centrifuge all production to ensure complete separation of the phases after varsol had been added.

A Heise gauge or mercury manometer, depending upon the magnitude of the pressure drop expected, was used to obtain the pressure drop across the core.

The viscosity profiles shown in Appendix A were obtained using Cannon-Fenske viscometers in a liquid temperature bath to give the range of temperatures needed. The viscosity of water was taken from Perry and Chilton[17].

Interfacial tensions were all measured with a Du Nouy tensiometer and the values reported are actually arithmetic averages of a series of tests for each pair of fluids.

B. SAND

The sand used for all runs was Fisher Scientific silica (S-151). This sand had a grain size range of 80-120 mesh and no further sieving was performed. The sand was used as purchased, except for heating it to 1000°F to rid it of any organics that may have been present on the surface of the sand grains.

C. FLUIDS

Distilled water was used as connate water and displacing water in all experimental runs.

Two oils were chosen for this group of tests. The first, a Dow Corning 200 fluid, had a viscosity of 500 c.s. at 70°F (21.1°C). This is a silicone base oil which exhibits a rather flat viscosity-temperature profile, a low surface tension and a low vapor pressure. In short the properties of the fluid are quite stable and will not change greatly from run to run. However, from personal communication with Dr. Bentsen, some experimental measurements indicate that Dow Corning fluids deteriorate with age and possibly are dilatant. As a consequence these fluids may exhibit dilatant rather than Newtonian behavior.

The second oil chosen for this series was a Wainwright crude oil which contained about 6% water "as received" from the field. By applying heat and a vacuum at the same time the water was removed from the oil. The tests were run using this water free crude, which had a viscosity of 1080 c.s. at 70°F.

A summary of some fluid properties is available in Appendix A.

IV. EXPERIMENTAL PROCEDURE

A. PACKING OF THE CORES

The silica sand used for all runs was placed in an oven at 1000°F (538°C) for a minimum of 48 hours to burn off any organics that may have been on the sand grain surfaces. Imbibition tests carried out by Wiborg[23] indicate that this procedure makes this type of sand water-wet. When the sand had been "fired" in the above manner it was then ready to be packed into a core holder. One endcap was installed on the coreholder with the screens in place and it was then strapped to a bench, capped end down, after making note of the end cap length and volume. Mechanical vibrators operated by compressed air were affixed to the vertical core holder. Sand was added to the coreholder and the weight of any sand added was recorded. The grain volume could be estimated from its weight knowing the density of silica sand as 2.65 gm/cc. The pore volume was then calculated. The vibrators were left on at night (periods of 8-10 hours) until no more subsidence took place. This usually took 3-4 nights with the sand level being "topped up" each day. Blows with a rubber hammer also helped settle the sand. The upper endcap was installed with the screens and then the overall length of the coreholder was established, including the endcaps. The total

length minus the two endcap lengths yielded the sandpack length.

B. SATURATING THE PACKED CORE

The packed core was then attached to a vacuum pump and the core evacuated until the absolute pressure within the coreholder was 1-2 mm of mercury. The core was then placed in a vertical position and saturated with deaerated distilled water. The water was deaerated beforehand by drawing a vacuum on the water for 2-3 hours. The vertical position of the core is important for the simple reason that if any vapor does come off this water as it is introduced to the evacuated core it will be easier to extract out of the system in this position. Also no air will be trapped in the upper section of the core as could happen when the cores were saturated in the horizontal position.

When pressure started to build in the system the outlet valve was opened slightly to allow water to pass through into a graduated cylinder. This outlet valve was controlled so that a pressure of 60-70 psig was maintained on the system until at least one pore volume was flowed through. It was hoped that this procedure would put any vapor back into solution or at least make vapor bubbles, if any, in the core small enough to be displaced out of the system. The resulting core would be completely liquid

filled. The pump reading gave the total amount injected and the ejected fluid was measured, with the difference being the pore volume after allowing for the volume of the endcaps and fittings. These pore volumes, from the material balance when compared to the pore volumes established by using the weight and density of the sand, were consistently within 2% of each other.

Water was flowed through the core and the pressure drops were noted for a number of different rates and these were used to calculate an absolute permeability for the sandpack. A complete table of sandpack properties can be found in the next chapter. The reported permeability is the arithmetic average of a number of tests conducted on each core.

Oil was forced downward through the core displacing water out of the lower end. A volumetric balance was kept on the oil and water ejected and the respective initial saturations could then be calculated. The oil injection rate into the 2 inch cores, for the Dow Corning fluid, was 100 cc/hr. For the Wainwright crude oil injection was maintained at 80 cc/hr because of its greater viscosity. To account for a change in diameter the injection rate into the 4-inch core was 400 cc/hr. In the case of the smaller diameter cores approximately 1000 cc's of oil were injected. It was found that very little water was produced after the

oil broke through at the lower end of the core. The pressure drop across the core was also noted at this point so that an effective permeability to oil at initial water saturation could be calculated.

C. DISPLACEMENT TESTS

The core was now at initial conditions and ready for a waterflood to begin. The coreholder was placed on the automatic rotating device which was in a horizontal position for this set of experiments. The automatic collection device containing the centrifuge tubes was placed in position at the outlet end of the core and the pressure gauge was connected in at the upstream end of the core. The selected injection rate was obtained by choosing the correct gear ratios on the Ruska pump, and the flood was started. At convenient intervals, the volumes of produced oil and water were recorded, as well as the pressure drop, the amount injected and the time. The flood was continued usually until about 3 or 4 pore volumes had been injected. The runs were continued until very little more oil was produced and this point was then used to obtain K_{rw} at So_r.

When the run had been completed the coreholder was completely cleaned and washed and then repacked with new sand and the procedure repeated.

V. DISCUSSION OF RESULTS

A. SANDPACK PROPERTIES

A completely new sandpack was packed for each experimental run and the sand was not reused. This procedure should result in a more uniform wettability for the system and provide support for the fact that decreases in recovery with rate are simply not wettability changes. By packing a new core for each run much more time was consummed per run than during a simple resaturation procedure. However, if the core properties can be reproduced within reason, the results should be able to be interpreted with much more confidence. Table 1 lists the sandpack properties from run to run for the entire set. A "200" series was completed using two inch O.D. coreholders with slightly different I.D.'s as can be noted from the cross-sectional areas and a "400" series consisting of four tests was carried out on a four inch O.D. coreholder. The sandpack lengths are very uniform averaging 107.47 cm and these variations in length are caused by a slightly different amount of sand being added in the packing process from run to run. The porosity was very uniform as well, averaging 36.4%. The porosity of run 221 was a full 2% above this average. This run will be discussed later since it also exhibited an extremely low initial water saturation.

TABLE 1

CORE PROPERTIES

Sand - Fisher Scientic Silica (S-151)
80-120 mesh
- completely new sandpack for each run.

Run #	Cross Sectional Area (cm^2)	Sandpack Length (cm)	Porosity (%)	Absolute Permeability (Darcies)
201	19.32	107.15	36.5	15.40
202	19.32	107.95	36.9	17.34
203	19.32	108.61	36.7	16.39
204	19.32	107.73	37.2	13.75
205	19.32	107.75	36.0	8.43
206	19.01	107.31	36.1	7.56
207	19.32	107.72	36.8	8.54
208	19.32	106.92	38.0	16.72
209	19.01	107.81	35.5	8.66
210	19.32	107.04	36.0	12.45
211	18.93	107.19	36.5	12.64
212	18.93	108.12	36.3	12.00
213	19.01	107.02	35.2	10.34
214	19.32	107.82	36.2	8.56
215	19.32	107.50	35.5	8.33
216	19.01	106.52	35.2	8.17
217	19.32	107.25	36.0	9.42
218	18.93	108.02	35.5	9.66
219	19.32	107.37	35.7	11.43
220	19.32	107.21	37.0	12.52
221	18.93	107.76	38.4	15.09
401	74.36	107.42	37.0	16.46
402	74.36	107.34	37.1	18.28
403	74.36	107.01	37.4	11.33
404	74.36	107.17	36.2	10.39

There was much more scatter in the permeability from run to run as can be seen in Table 1. It was felt that these changes in permeability were due to slightly different average grain sizes in the different shipments of sand and since the sand was used just as it was supplied these grain size inconsistencies appeared to have affected the sandpacks from run to run. It is recommended that in the future, shipments of sand be sieved to a narrower grain size range before being used in displacement experiments to try and obtain a more reproducible permeability.

The dimensionless scaling coefficient that was used in this work to scale the results contains the permeability as a parameter and therefore these changes should not affect the interpretation of results unless a change of displacement mechanism takes place due to this change in permeability.

B. FLUID PROPERTIES

The fluid properties for the Dow Corning 200 experiments (runs 201-209 plus 401-404) were very consistent and the viscosity can be considered to be constant for the entire set of experiments. A temperature fluctuation of a few degrees made some difference in the Wainwright crude oil viscosity as can be seen from the properties listed in

Table 2. However, these fluctuations in viscosity do not appear to be great enough to have affected the displacement tests significantly if runs 215 and 216 are examined (see Table 2). These two sandpacks exhibit very close to the same porosity and permeability and the difference in displacement rates is not great (100 cc/hr and 80 cc/hr, respectively). However, the difference in oil viscosities between the two runs is close to the maximum variation for the entire series (821 cp and 1028 cp, respectively) yet the recovery is identical at breakthrough being 23.8% I.O.I.P.

C. DISPLACEMENT TESTS WITH DOW CORNING

A summary of the displacement test data appears in Table 2. Individual recovery curves for each run can be found in Appendix B and tabulated recovery data for each run can be found in Appendix D.

From Table 2, the water saturations for the Dow Corning runs can be seen to be relatively constant, ranging from 9.7% to 12.5% over the series and averaging just over 11%. The problem that Wiborg[23] had with rising water saturations does not occur in these tests. Two possible reasons for the elimination of this problem are:

1. With a new sandpack for each run any material balance errors are not carried forward to the next run.

TABLE 2.

DISPLACEMENT TEST SUMMARY

Run	Oil	Oil Viscosity (cp)	μ_o/μ_w	Swi (%)	Koi (Darcy)	Q (cc/hr)	V x 10^3 (cm/sec)	RECOVERY (%IOIP) B.T.	RECOVERY (%IOIP) WOR=6	RECOVERY (%IOIP) WOR=20	RECOVERY (%PV) B.T.	RECOVERY (%PV) WOR=6	RECOVERY (%PV) WOR=20	I x 10^3
201	DOW CORNING 200	533	549.6	9.80	13.35	2.5	0.036	27.22	34.00	40.20	24.55	30.67	36.26	2.84
202		533	541.1	11.26	13.55	10.0	0.144	24.41	28.9	35.7	21.45	25.40	31.37	11.02
203		533	541.1	11.45	14.31	160.0	2.300	19.74	29.4	37.3	17.43	26.03	33.03	182.40
204		533	541.1	12.50	12.12	300.0	4.313	16.98	28.0	35.1	14.86	24.51	30.72	373.68
205		533	549.6	11.44	7.30	800.0	11.502	16.28	27.1	36.7	14.42	24.00	32.50	1261.80
206		533	533.0	10.58	6.66	20.0	0.292	25.87	26.0	40.9	23.13	23.45	36.57	33.73
207		533	541.1	11.86	8.18	560.0	8.052	16.17	29.5	37.1	14.25	26.0	32.70	877.60
208		533	541.1	12.46	14.95	50.0	0.719	20.90	31.4	39.3	18.30	27.49	34.40	55.59
209		533	549.6	9.70	8.18	15.0	0.219	23.77	29.9	40.2	21.47	27.00	36.31	23.74
401		533	549.6	10.20	15.00	10.0	0.037	16.07	26.7	32.6	14.43	23.98	29.28	2.925
402		533	549.6	10.80	15.73	40.0	0.149	25.11	28.9	33.6	22.31	25.68	29.86	11.196
403		533	533.0	11.73	10.09	600.0	2.241	15.2	28.3	36.5	13.42	24.98	32.22	212.66
404		533	549.6	10.34	9.89	1120.0	4.184	15.1	29.9	36.7	13.33	26.39	32.40	415.16
210	WAINWRIGHT CRUDE	947	980.3	8.34	10.39	15.0	0.216	8.52	25.7	42.4	7.81	23.46	38.88	24.42
211		947	980.3	9.68	10.41	25.0	0.367	8.48	19.0	44.1	7.66	17.16	39.83	41.28
212		947	980.3	9.93	11.12	50.0	0.734	12.71	21.3	----	11.45	19.19	-----	85.49
213		987	1021.7	9.28	9.16	7.5	0.110	8.50	24.8	----	7.71	22.49	-----	13.64
214		947	980.3	9.34	6.06	800.0	11.502	41.47	52.1	65.2	37.60	47.23	59.11	1509.0
215		820.7	873.1	9.41	6.40	100.0	1.438	23.80	36.55	50.3	21.56	33.11	45.56	199.0
216		1027.5	1045.3	9.10	7.02	80.0	1.169	23.77	35.0	44.8	21.60	31.81	40.72	162.6
217		1132.9	1132.0	7.30	7.36	200.0	2.876	33.37	45.4	49.6	30.94	42.09	45.99	375.0
218		1027.5	1045.3	7.03	9.22	400.0	5.870	31.04	49.1	52.5	28.86	45.65	48.81	761.4
219		947	980.3	7.13	8.03	600.0	8.627	16.22	34.7	39.5	15.06	32.23	36.68	1022.5
220		1083.0	1085.2	7.18	9.36	800.0	11.502	31.10	41.5	45.7	28.87	38.52	42.42	1300.76
221		1027.5	1045.3	5.40	13.24	800.0	11.739	33.33	39.8	42.2	31.09	37.13	39.37	1215.44

2. Possible wettability changes are eliminated from run to run because the oil is not in contact with the rock for long periods of time as is the case if numerous runs are conducted on the same sandpack.

Material balance problems are present although they were not severe over the course of a run. By scanning some of the tabulated data in Appendix D, it can be seen in some runs that the average saturation (material balance calculation) sometimes decreases for one step and then continues to increase. As we inject water and produce oil and water this saturation calculation should <u>always</u> be increasing until the ultimate oil recovery is reached, so a decrease in this average saturation column indicates a slight material balance error. In the case of Wiborg[23] this cause of error should not be great since most of his runs were terminated just past breakthrough. However, in this set of experiments production was continued far past breakthrough and in some runs, possibly one hundred centrifuge tubes would have to be read and the errors could build over this length of time. This should not cause serious problems if the material balance is only kept for one run.

The problem of wettability changes in unaged cores is a major one if more than one run is to be made on the same sandpack. The Dow Corning fluid is especially bothersome in this respect. It was found that a short period of

aging (about 15 days) reversed the wettability of the sandpack from water-wet to oil-wet. Run 401 was saturated and then left for about 15 days before the displacement experiment was run. When this point was plotted on Figure 2 it was very anomalous with respect to the rest of the data. If the recovery curve of run 401 is compared with the curve of 402 (Figures B-22 and B-23, respectively) it can be seen that run 401 behaves quite differently from the other runs. The breakthrough recovery is very low and the subordinate recovery subsequent to breakthrough almost equals the breakthrough recovery. This is not characteristic of water-wet systems. Water-wet systems are characterized by a late breakthrough recovery with a very flat subordinate production history. All of the other curves with Dow Corning at low rates show the latter type of behavior and these were interpreted to be water-wet.

Further to this argument on wettability changes a study was carried out on the used sand from one of the tests. The used sand from the Dow Corning fluid runs was soaked in recommended solvents and then steamed and rinsed in soap and water in an attempt to see if it could be cleaned. A simple bench imbibition test showed that the used sand would not imbibe any water, whereas before it was used it would imbibe water spontaneously.

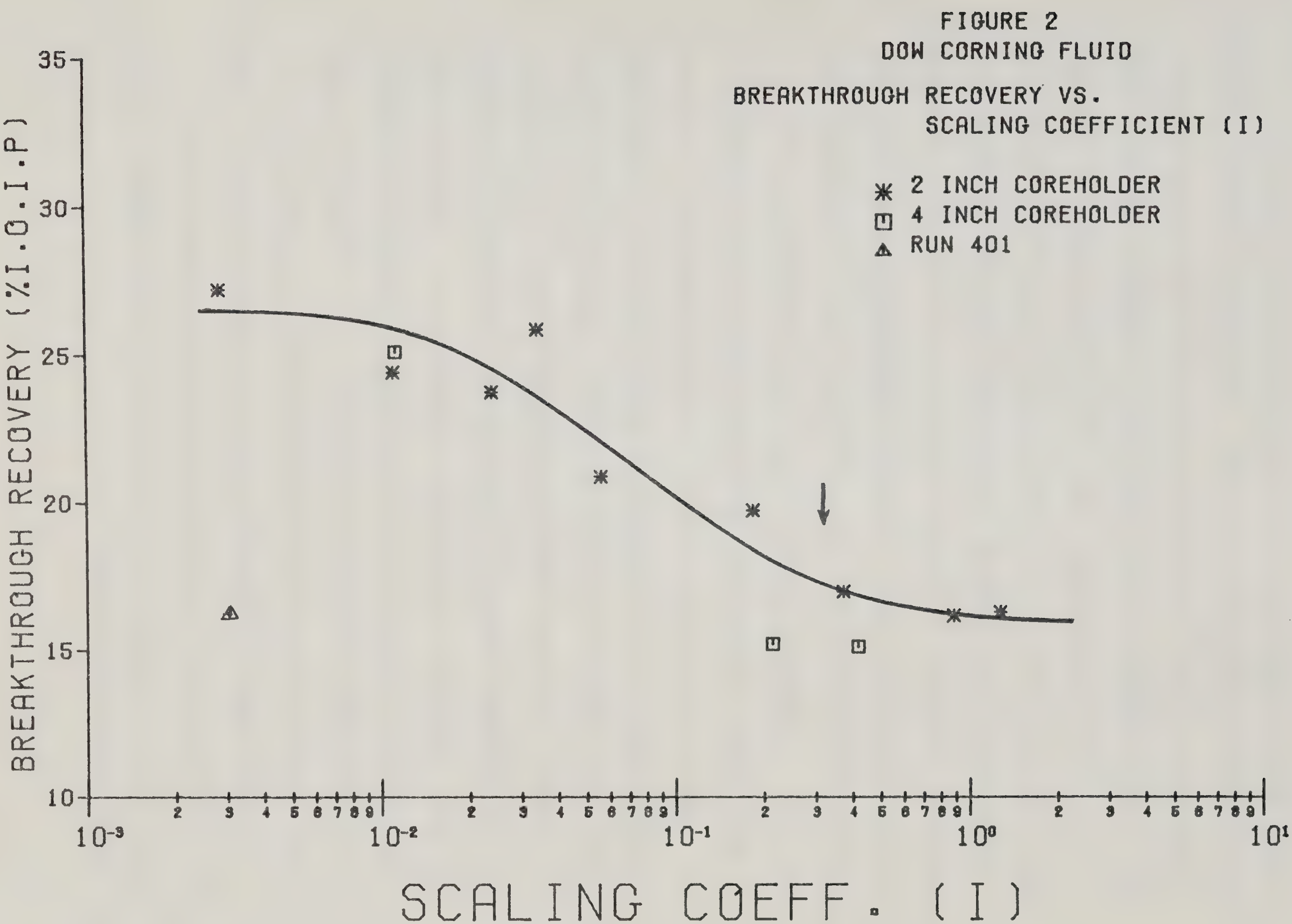


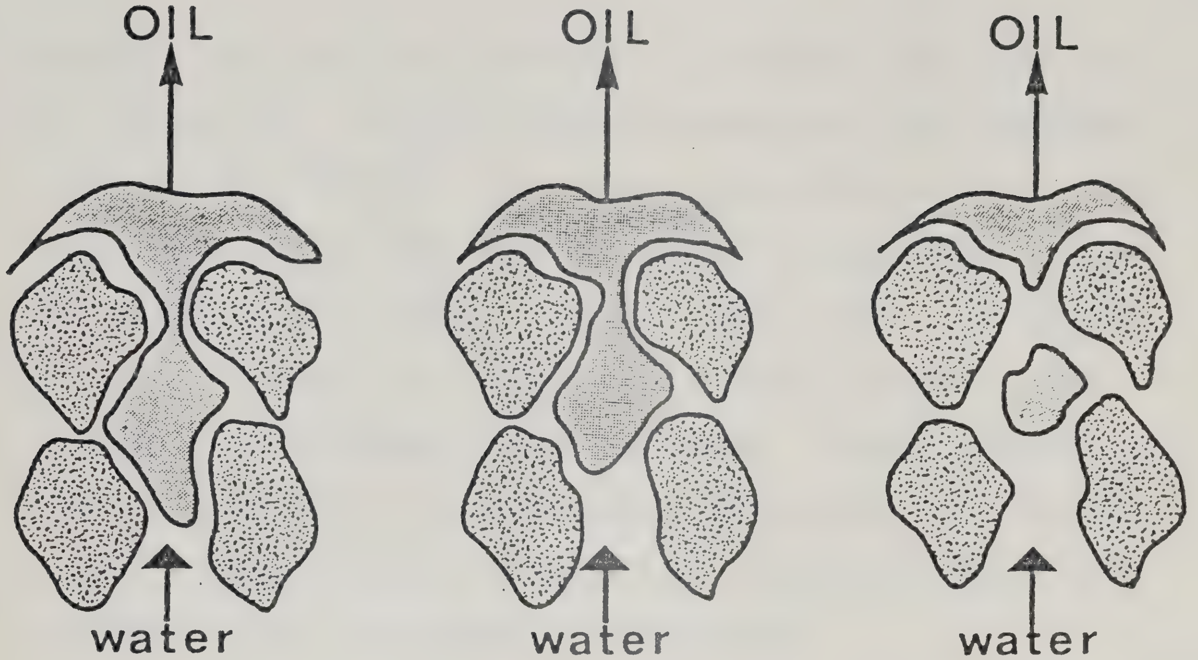
FIGURE 2
DOW CORNING FLUID
BREAKTHROUGH RECOVERY VS.
SCALING COEFFICIENT (I)
2 INCH COREHOLDER
4 INCH COREHOLDER
RUN 401
BREAKTHROUGH RECOVERY (%I.O.I.P)
35
30
25
20
15
10
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
SCALING COEFF. (I)

The experimental results involving Dow Corning fluid are presented in Figure 2. The plot represents breakthrough recovery versus the scaling coefficient "I". The rate of injection was changed to vary the scaling coefficient. As the rate was increased a decrease was observed in the breakthrough recovery of some 10% of the oil in place. The experimental data were correlated by the use of the dimensionless "I" function which is a simplification of Geertsma's (L_t) function as explained earlier. Run 401 is anomalous when compared to the other data and was discussed previously.

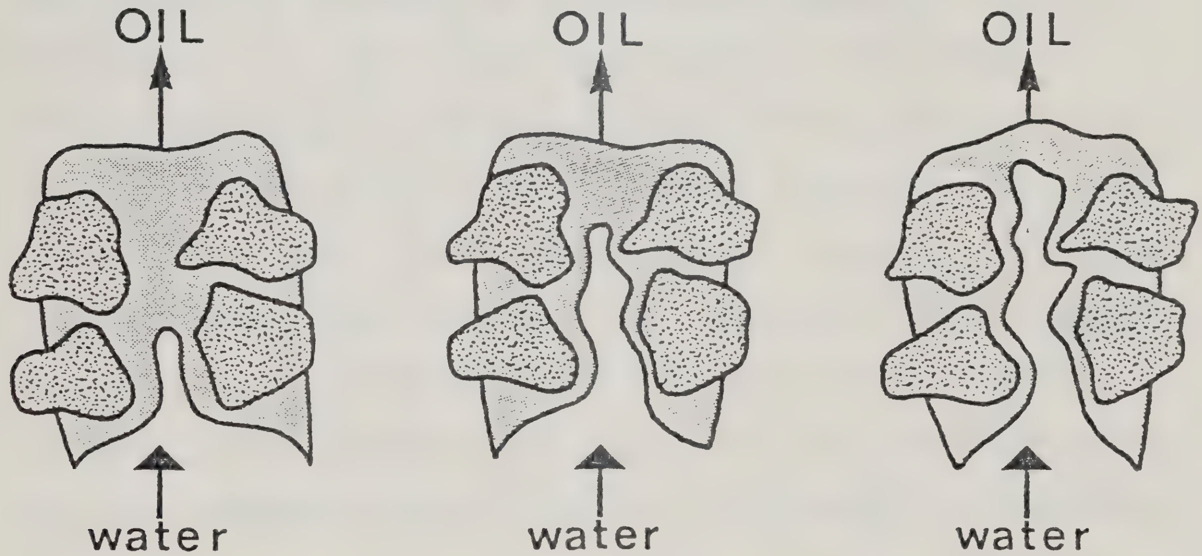
The value of "I" was increased by increasing the rate of injection and holding the other parameters relatively constant. Although the data in the two inch core tends to be scattered at lower rates a general trend of decreasing recovery can be seen. This decrease in recovery has been attributed to viscous fingering within the core. From Equation (3), for the average peak to peak distance between fingers, an increasing displacement velocity and an increasing viscosity difference both decrease the distance between fingers, λ_m. Because of the large injection rates and large viscosity difference employed in this study the peak to peak distance of fingers should be very small.

It is interesting to note that the recovery from run 401 (at breakthrough), which was considered to be oil-wet, is very close to the recovery for the two four inch core

runs at high rates. This can be explained if the work of Raza et al.[19] is examined. If the different displacement characteristics are studied in Figures 3 and 4 (reproduced from reference 19), a fundamental difference between waterflooding in an oil-wet and a water-wet system can be seen. In Figure 3, where the rock is water-wet, the invading water prefers to advance along the walls of the pores and likes the smaller pores as well, since the capillary forces are higher. When the end of a pore is reached the water cusps in at the outlet and traps a droplet of oil in the pore. In an oil-wet system (Figure 4) the water prefers to stay away from the solid surface and moves up the center of the larger pores thereby breaking through much earlier than in the water-wet case. It seems plausible that if water were injected into a water-wet core at a very high rate the water would not have time to imbibe around the edges of pores or into the smaller pores. The capillary forces at high rates would not be as important, thus imbibition into these smaller pores would probably not be accomplished before breakthrough. The path of least resistance would be followed in this case, right up the center of the pores. In this case, although the system is water-wet it behaves as though it were oil-wet for the first part of the flood. The water advances up the center of the pores at first like a flood in an oil-wet



DISPLACEMENT OF OIL BY WATER (water-wet sand, $\theta = 0°$) FIG. 3.



DISPLACEMENT OF OIL BY WATER (oil-wet sand, $\theta = 180°$) FIG. 4.

-taken from Raza et. al. (19.)

system. As the flood progresses, the system has more time to imbibe water into any smaller pores that were bypassed prior to breakthrough. So in the later stages of the flood, imbibition around the smaller corners of the pores is taking place as in a flood in a water-wet system. It should be mentioned that the wettability has not reversed, the system is only <u>acting</u> oil-wet at first. Craig[6] states that at high rates of displacement wettability characteristics do not have time to manifest themselves which is in agreement with the preceding explanation.

Capillary end effects can be ruled out as an explanation for the decrease in breakthrough recovery observed. Because of the long system used and the large viscosity ratios used in this study capillary forces should be very small compared to the viscous forces. Rapoport and Leas[18] show that the end effect diminishes as the rate of injection is increased. They also show that capillary forces decrease as the rate is increased until some stabilized value is reached. After some rate was exceeded they found the recovery was constant because of this stabilization of capillary forces in the flood front. At higher viscosity ratios they did observe a decrease in recovery but explained it as an inlet end effect. Because of the design of the end caps of the coreholders for this study and the size and length of the system these end effects are very small and would not

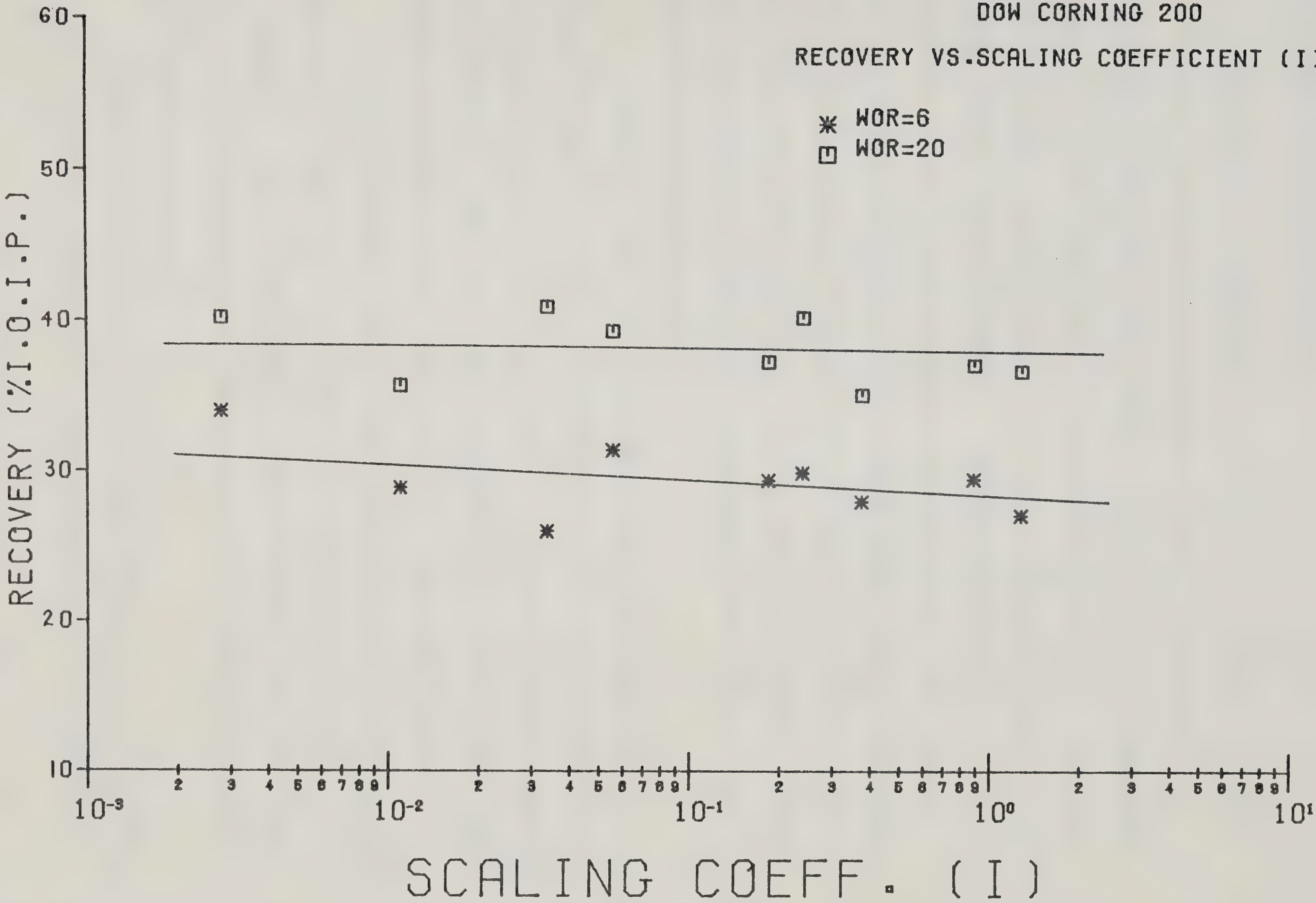
account for the 10% decrease in breakthrough recovery.

In Figure 5 the recoveries at water to oil ratios of 6 and 20 have been plotted versus the scaling group "I". The characteristic decline of the breakthrough recovery curve observed in Figure 2 was not observed. Only a very slight decrease, if any, can be seen at WOR = 6. The recovery at WOR = 20 is constant with no decrease observed.

This indicates that rate of injection is only affecting the recovery early in the life of the flood and as the flood progresses the effect of rate on recovery disappears.

In waterflooding a water-wet system the residual oil is trapped as globules in a discontinuous state (Figure 3), resulting in a small amount of subordinate production. Therefore, a low breakthrough recovery should result in a low ultimate recovery. From Figure 5 it is apparent that this is not the case. However, if the water flowed up the center of the pores at high rates of injection, at water breakthrough the remaining oil is left in a continuous state around the sand grains (Figure 4). As subsequent injection takes place the water has more time to imbibe around the sand grains. Substantial subordinate production could occur resulting in the same ultimate recovery as observed at low rates.

FIGURE 5
DOW CORNING 200
RECOVERY VS.SCALING COEFFICIENT (I).



D. DARCY LAW CROSS-PLOTS

Following a suggestion of Bentsen[2] a simple cross-plot using Darcy's Law was constructed for the two and four inch cores with Dow Corning fluid. If the injection rate, Q, is plotted versus the pressure drop, Δp, for the same average saturation in the core a straight line with slope, $KA/\mu L$, should result. The permeability, K, is considered to be a function of saturation only, so if the Q and Δp values are taken at the same value of W_i (dimensionless pore volumes injected) the average saturation should be comparable from run to run. If there is nothing affecting the behavior other than saturation, then these plots should be straight lines.

Figures 6 and 7 are the Darcy Law cross-plots. In these figures the rate of injection is plotted versus the pressure drop and points of equal volumes of water injected are joined. Each line then represents the same water saturation in the core at the different injection rates.

From Figures 6 and 7 there appears to be two distinct regions on the plots. Darcy's Law holds until some "critical" rate is exceeded at approximately 265 cc/hr and then the conductivity of the system continually decreases as rate in increased.

Figure 6 is a plot of the data obtained from the two inch cores and Figure 7 is a plot from the four inch core

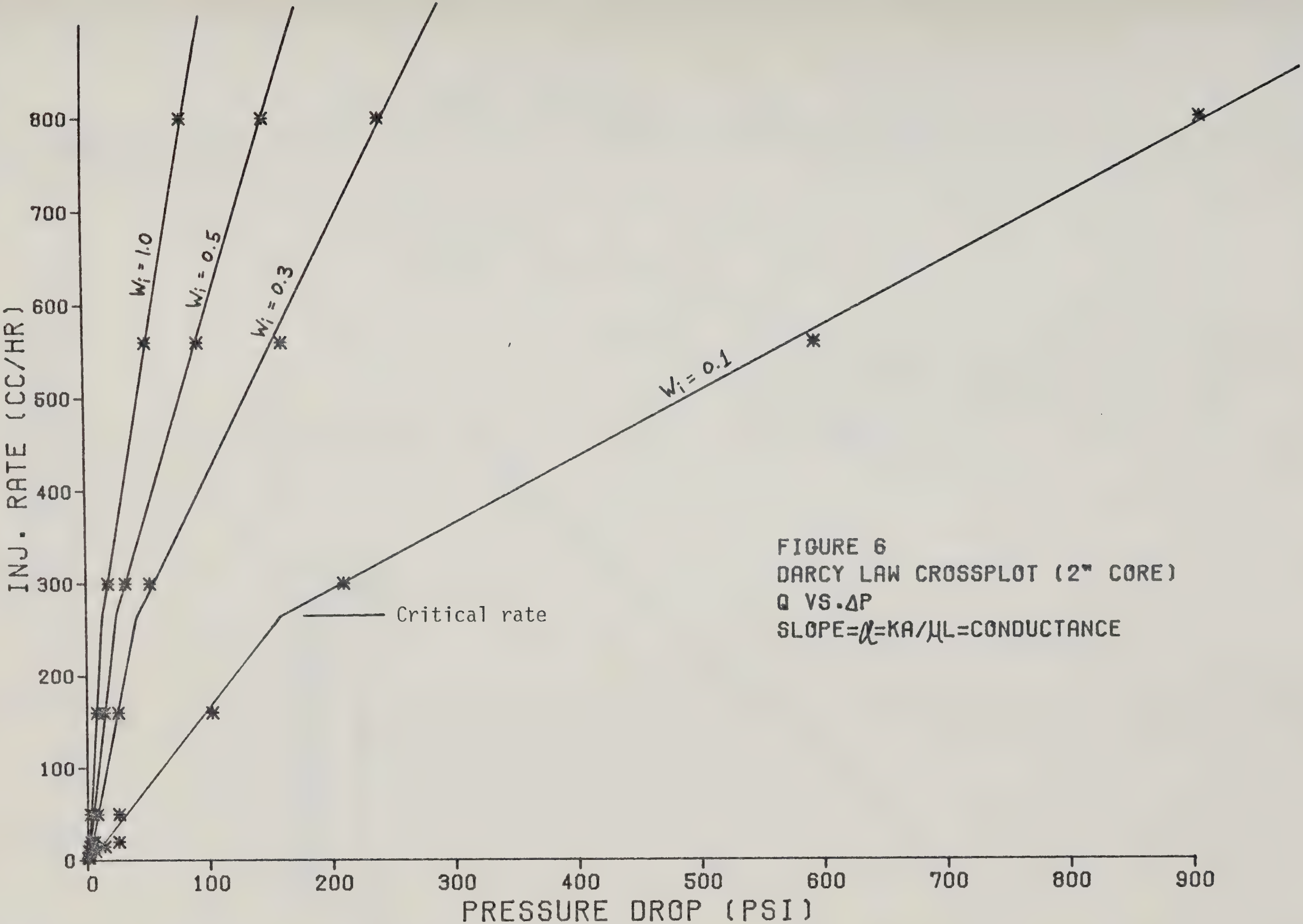


FIGURE 6
DARCY LAW CROSSPLOT (2" CORE)
Q VS. ΔP
SLOPE=α=KA/μL=CONDUCTANCE

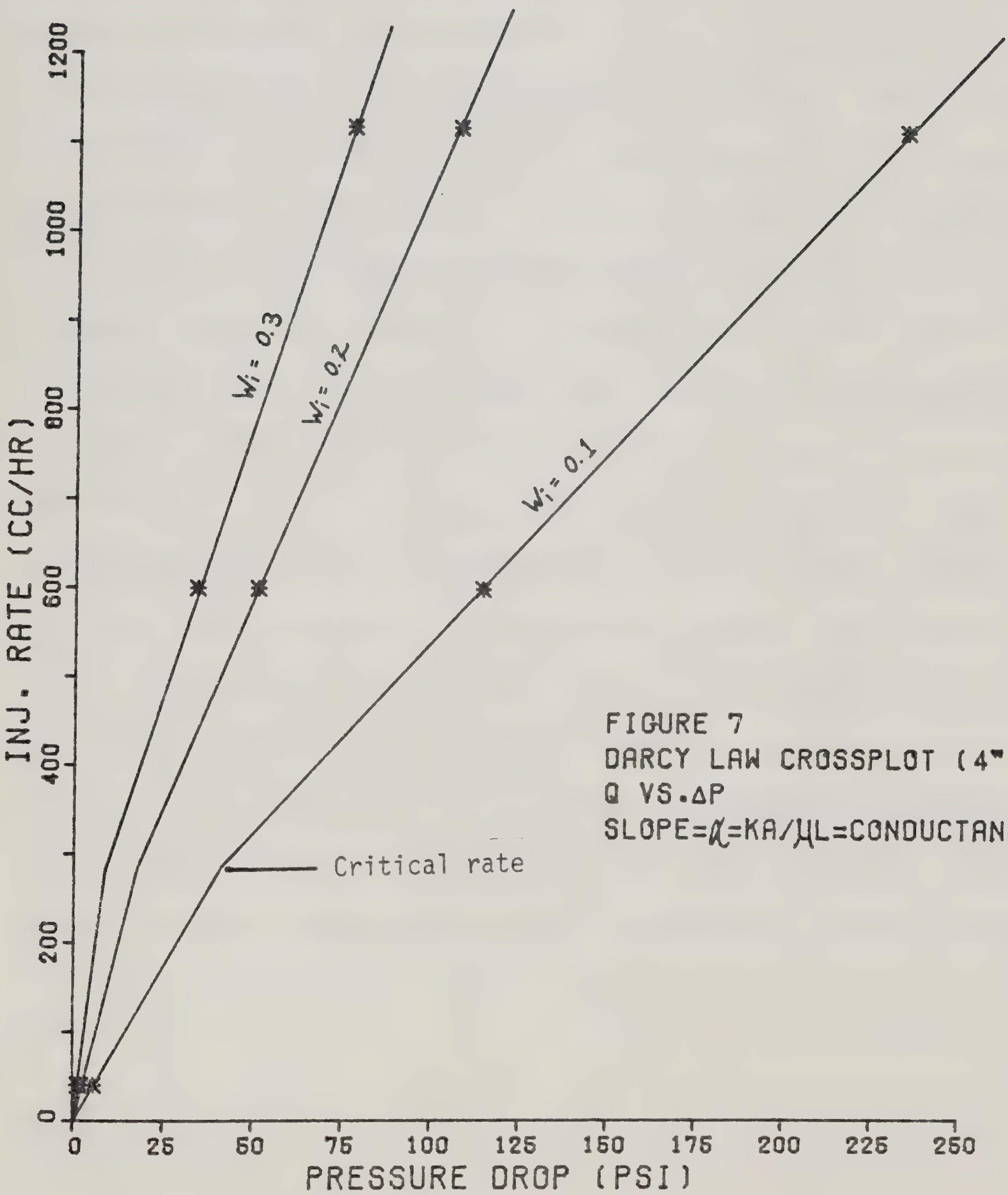


FIGURE 7
DARCY LAW CROSSPLOT (4" CORE)
Q VS. ΔP
SLOPE=α=KA/μL=CONDUCTANCE

data. The slopes differ by nearly a factor of four between Figures 6 and 7 which is to be expected since the ratio of cross-sectional areas is nearly four.

It was thought that these correlations might be used to explain the decrease in recovery in Figure 2. However, the break in the relationship does not correlate with the observed decrease in recoveries. The critical rate shown in Figures 6 and 7 is approximately 265 cc/hr. This rate corresponds to a scaling coefficient value of 0.3113 and is indicated by the arrow in Figure 2. Most of the decrease in recovery has already occurred before this change of conductivity takes place. It appears that this "critical" rate occurs very close to the rate where the breakthrough recovery levels off and becomes constant. At this point, according to Chouke[4], there are numerous fingers in the system and recovery is independent of the scaling factor. Perhaps there is severe interference between the fingers after this point is surpassed so that the conductivity is continually decreasing and there is no effect of this decrease of conductivity on recovery. A changing mobility ratio could have some affect on these correlations, however, there was no evidence that such a change was taking place.

E. RELATIVE PERMEABILITY CALCULATIONS

In another attempt to see what changes occur from the low rates to the high rates of injection, the theory published by Johnson et al.[11] to calculate relative permeabilities from the unsteady state displacement data, known as the external drive technique, was employed. A complete derivation can be found in Appendix C as well as the "curves" generated by these calculations.

The values of relative permeabilities calculated by this technique are not considered reliable. Wild fluctuations appear that make fitting a curve through the points rather difficult. It was hoped that changes in the relative permeability curves would provide some additional evidence to explain the decreasing recovery observed. However, no conclusions could be drawn from these results.

Archer and Wong[1] suggest that the poor definition of permeability can be encountered in strongly water-wet homogeneous cores. These anomalous curve shapes may be associated with laboratory-observed water breakthrough occurring at a different time than actual water arrival at the down stream end of the core.

F. CALCULATION OF THE CHOUKE CONSTNAT

From Figure 2 the point of decrease in recovery on the curve corresponds to a scaling value of 0.015 and if

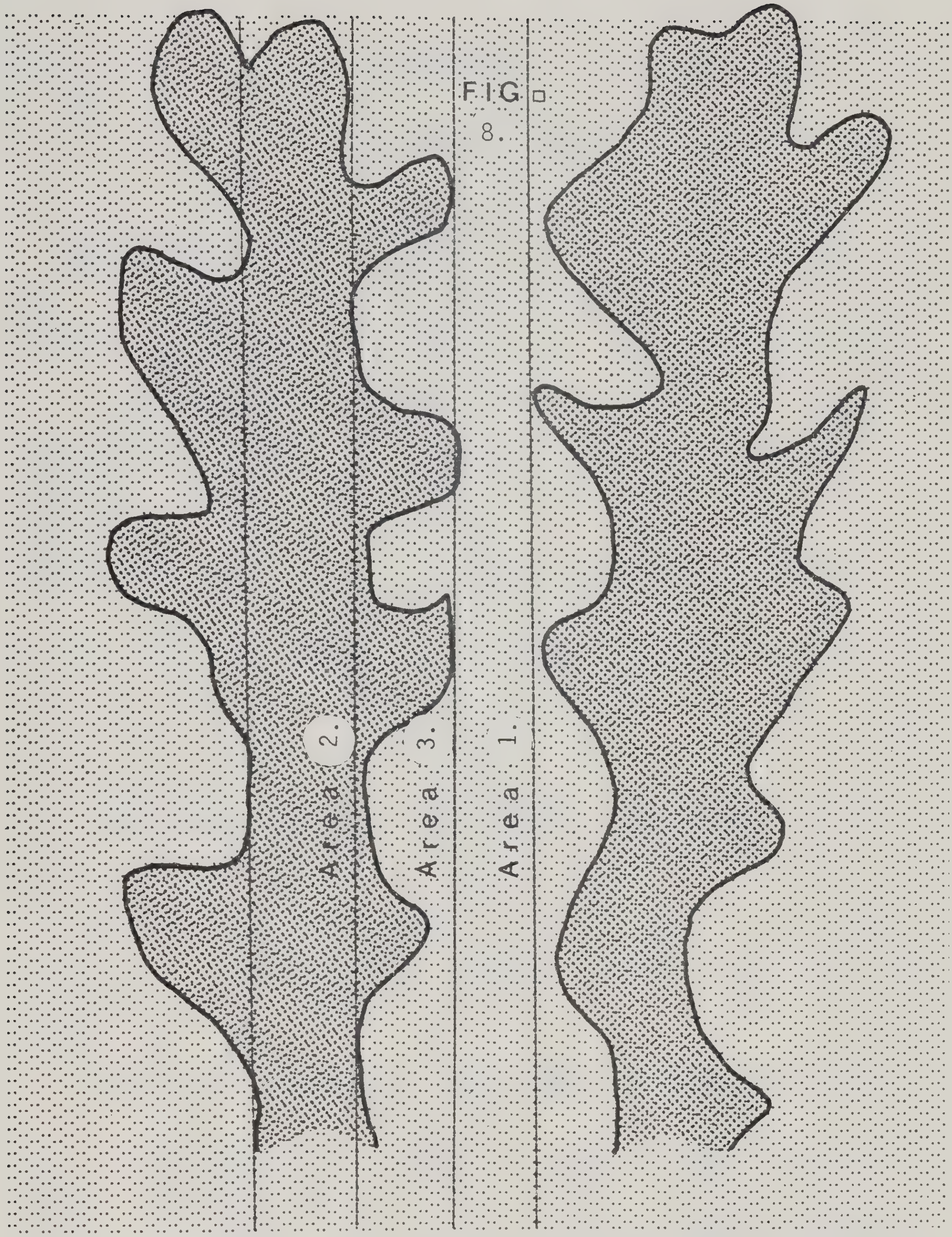
this value is used in Equation (6) the value of the Chouke constant (C) can be calculated. If C can be found for a system then a prediction as to where fingering begins can be made.

There are two distinct sets of permeabilities present in the Dow Corning runs, one averaging 15.92 darcies and the other set averaging 8.3 darcies. For the 15.92 darcies set C was calculated to be 118 and for the 8.3 darcies set C was calculated to be 139. These are much higher values than those calculated by either Wiborg[23] or Kloepfer[13] and much lower than the value reported by Collins[5] (see Table 3).

de Haan[7] suggests that at low values of initial water saturation they obtained values of C around 100 which seems to fit well with the values found in this study. However, C is a constant only for one particular system. From Table 3, it is apparent that no generalizations can be made for assuming a value for C and calculating the point when fingering will begin in a system.

G. CALCULATION USING THE van MEURS AND van der POEL THEORY

The theory of van Meurs and van der Poel[21] was covered in detail by Wiborg[23]. The theory developed is based on an idealized picture of water fingers as shown in Figure 8. The areas occupied by the fingers and the areas occupied by the immobile oil and water can be stated in



IDEALIZED PICTURE OF WATER FINGERS SHOWING PROTRUSIONS AND OIL POCKETS

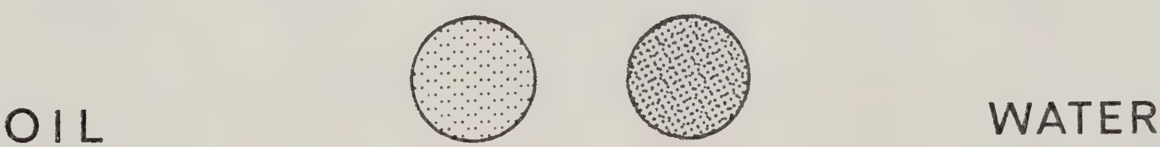


TABLE 3

CALCULATION OF C

Researcher		Viscosity Ratio	C	Sw_i
Wiborg	(CWO)	15.5	27.7	.15 -.30
	(MCT 5)	34.2	24.3	.12 -.25
	(DOW CORNING)	111.4	39.4	.09
Kloepfer		6.4	64	.10
Collins		292	250	.13
de Haan		4 & 25	30	-
this study		533	118-139	.11

TABLE 4

van MEURS RECOVERY CALCULATION (FRACTION P.V.)

$$So_r = 0.45$$

$$M = 533$$

		$Sw_m = Sw_i$		$Sw_m = 0.15$	
W_i	Experimental Np	Calc. Np	Δ Np	Calc. Np	Δ Np
B.T.	.1442	.1343	-.0099	.1721	+.0279
0.320	.1579	.1454	-.0125	.1796	+.0217
0.928	.2583	.1670	-.0913	.2003	-.0580
1.436	.2964	.1795	-.1169	.2123	-.0841
2.445	.3461	.1985	-.1476	.2305	-.1156
3.487	.3790	.2140	-.1650	.2452	-.1338

terms of the saturations of these respective areas.

- Area 1: represents the area outside the water fingers where oil flows unhindered.
- Area 2: represents the center area of the fingers where the water flows unhindered.
- Area 3: represents the area consisting of the edge zones of all the water fingers of the cross-section. In this area both water and oil are immobile.

Area 1 can be represented by the difference between the oil saturation and the residual oil saturation $(So-So_r)$ or with $So + Sw = 1$ then Area 1 is equal to $1 - So - Sw$. Area 2 could be represented by the difference between the water saturation and the immobile water saturation in Area 3 $(Sw-Sw_m)$. Using these relations and following the theory an expression for the breakthrough recovery is obtained where the recovery is expressed as a fraction of the pore volume.

The breakthrough recovery is given by:

$$Np_b = \frac{A^2}{MB}$$

and recovery after breakthrough is given by:

$$Np = Sw_m + \frac{1}{M-1} [2\sqrt{W_i MB} - W_i - B]$$

where

Np_b = breakthrough recovery (% P.V.)

Np = recovery after breakthrough (% P.V.)

A = $\sqrt{(M-1)B\ Sw_m} + B$

B = $1 - So_r - Sw_m$

M = μ_o/μ_w

W_i = pore volumes injected

The theory is developed with the assumption that fingers have already formed in the system and therefore this calculation should not be expected to predict the entire curve in Figure 2. It should only be expected that this theory would predict recoveries at the lower end of the curve where fingers are fully developed. To apply the theory a value for Sw_m must be found. A good first approximation would be to use the initial water saturation, and previous researchers have done this. However, if the fingers in Figure 8 are studied and if the fingers are considered to be without protrusions it can be seen that the value of immobile water in Area 3 is already Sw_i. With protrusions from the water fingers, the value of Sw_m must be somewhat higher than Sw_i.

van Meurs et al.[21] found that the theory correlated best with their experimental data when $Sw_m = 0.15$. For this study, first the calculation was performed using the value

of Sw_i for Sw_m and then another calculation was performed using $Sw_m = 0.15$. A value for So_r was obtained from run 202 where 7.2 pore volumes had been injected. Using this value of So_r and the two selected values of Sw_i the calculated performance for these two cases was compared with the experimental performance of run 205. Run 205 was one of the experiments conducted at higher displacement rates. The results of the calculation are listed in Table 4.

The breakthrough recovery is within 1% of the experimental value when using $Sw_i = Sw_m$ but the subsequent production history does not compare with the observed results. As the flood progressed the separation between experimental values and theoretical values increased. The theoretical values are compared with the experimental values in Figure 9. The subsequent recovery calculation produces a very flat profile as compared to the actual experimental data. From the calculations only about 8% of the pore volume is produced after breakthrough up to a $W_i = 3.487$ whereas the experimental results show 23.5% produced after breakthrough.

For $Sw_m = 0.15$ the breakthrough recovery could not be predicted nor could the subsequent production history. The same flat recovery profile is predicted but the breakthrough recovery is too high and the subsequent production predicted is too low.

Although the theory predicted the breakthrough recovery in the one case, the predicted recoveries after breakthrough

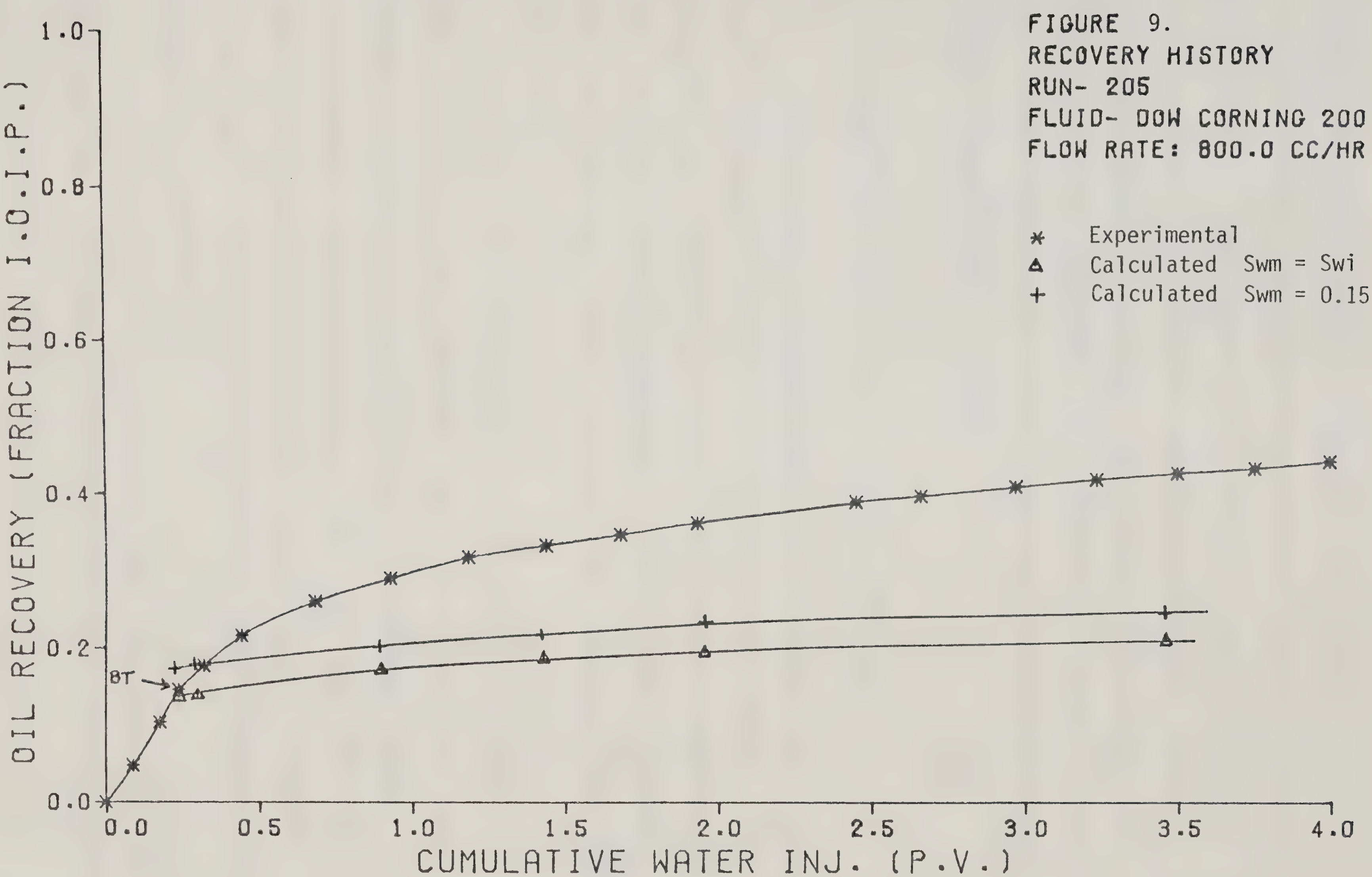


FIGURE 9.
RECOVERY HISTORY
RUN- 205
FLUID- DOW CORNING 200
FLOW RATE: 800.0 CC/HR
* Experimental
Δ Calculated Swm = Swi
+ Calculated Swm = 0.15
BT
OIL RECOVERY (FRACTION I.O.I.P.)
CUMULATIVE WATER INJ. (P.V.)
0.0
0.2
0.4
0.6
0.8
1.0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0

showed substantial error. Wiborg[23] could only predict the breakthrough recovery for one of his three oils using this method. From Figure 9 it should be noted that the small increase in the breakthrough recovery was present for both assumptions of Sw_m. This very flat profile is characteristic of systems with low mobility ratios. Possibly their theory may be more applicable to systems which exhibit lower mobility ratios.

H. DISPLACEMENT TESTS WITH WAINWRIGHT CRUDE OIL

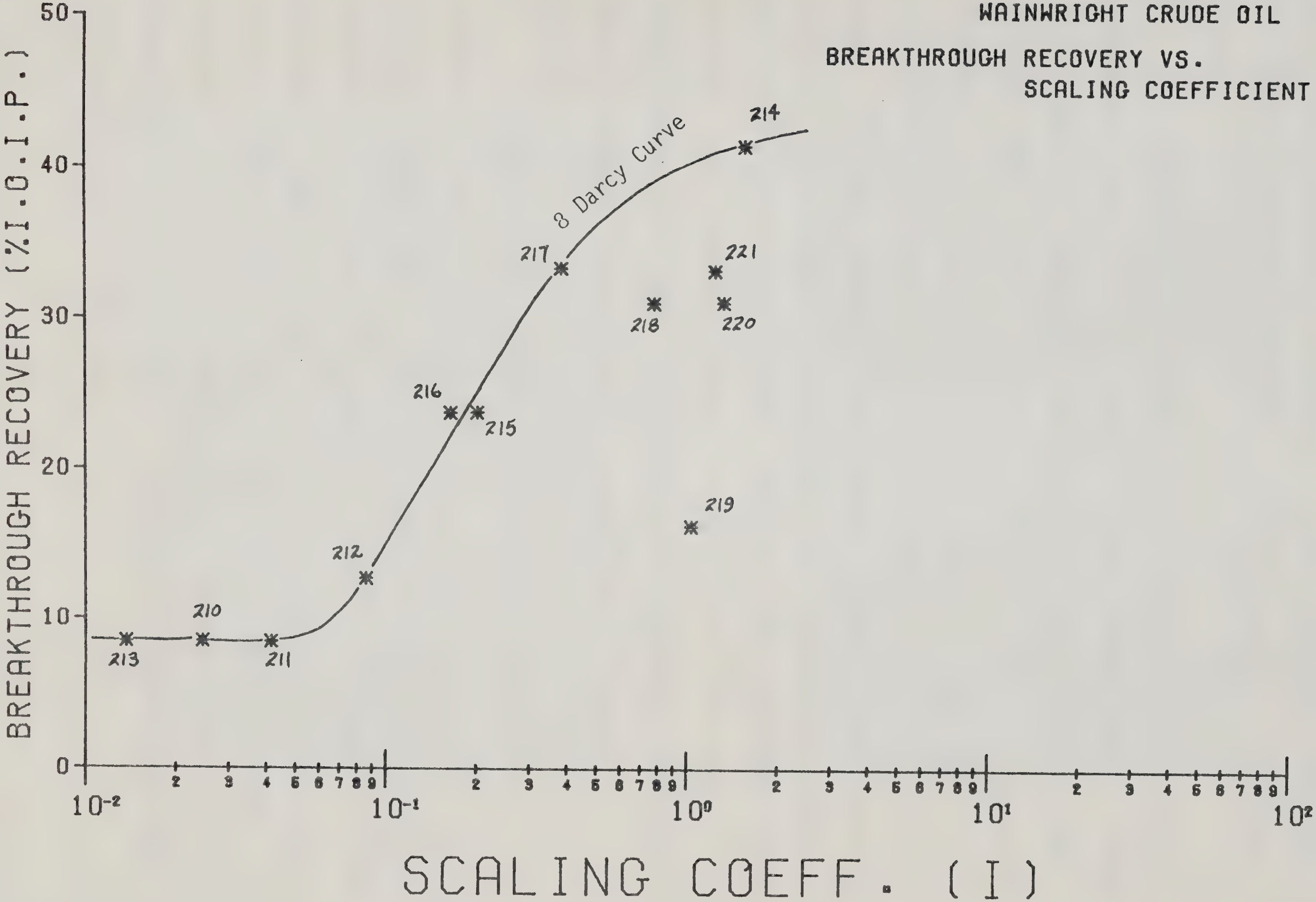
A second set of displacement experiments were run using a Wainwright crude oil in an attempt to observe the phenomenon of decreasing recovery for a more viscous crude oil. The oil had been dewatered to remove about 6% water that was contained within the crude when obtained from the stock tank.

The rates of displacement varied from 7.5 cc/hr to 800 cc/hr, which was practically the same range that was studied using the Dow Corning fluid. A summary of the displacement test data appears as the lower one-half of Table 2 and the complete recovery histories are tabulated in Appendix D. The individual recovery history curves can be found in Appendix B.

From Table 2 the oil viscosity can be seen to fluctuate much more than the viscosity of the Dow Corning fluid,

FIGURE 10.
WAINWRIGHT CRUDE OIL

BREAKTHROUGH RECOVERY VS.
SCALING COEFFICIENT (I)



but as was pointed out earlier in the discussion, the range of variation in this parameter does not seem to affect the results.

In Figure 10 the breakthrough recoveries are plotted versus the scaling coefficient "I" for the Wainwright crude oil. Again the scaling coefficient was varied by increasing the rate of injection with other parameters being held constant. As the rate of injection was increased the breakthrough recoveries increased dramatically over the range of rates studied. The observed behavior was contrary to what was expected after having just observed the behavior of the Dow Corning fluid. However, this increase in recovery has been attributed to water-in-oil emulsions being formed in-situ. Microscope photographs of the emulsions produced during run 220 can be seen in Figures 11 and 12.

Crude oil was produced until breakthrough of the emulsion. Pure water did not breakthrough before the emulsion in any of the runs. Once breakthrough of the emulsion had occurred all further oil production was in the form of this emulsion. Later in the life of the flood, pure water drops were produced between slugs of emulsion. The produced emulsion was found to contain 53.2% water by volume in a sample from one of the runs. The emulsion properties were not continuously monitored.

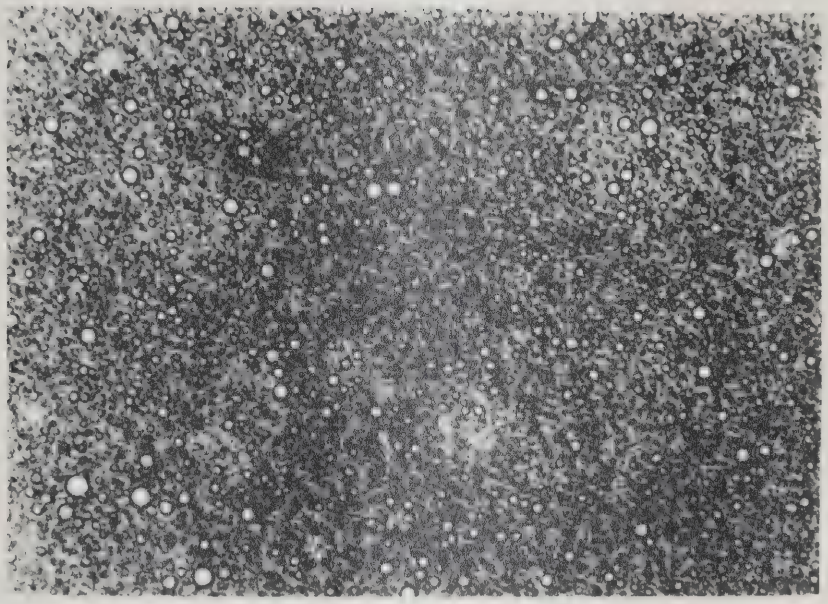


FIG. 11. Water-in-Oil Emulsion
Produced Run 220. Mag.(400x)

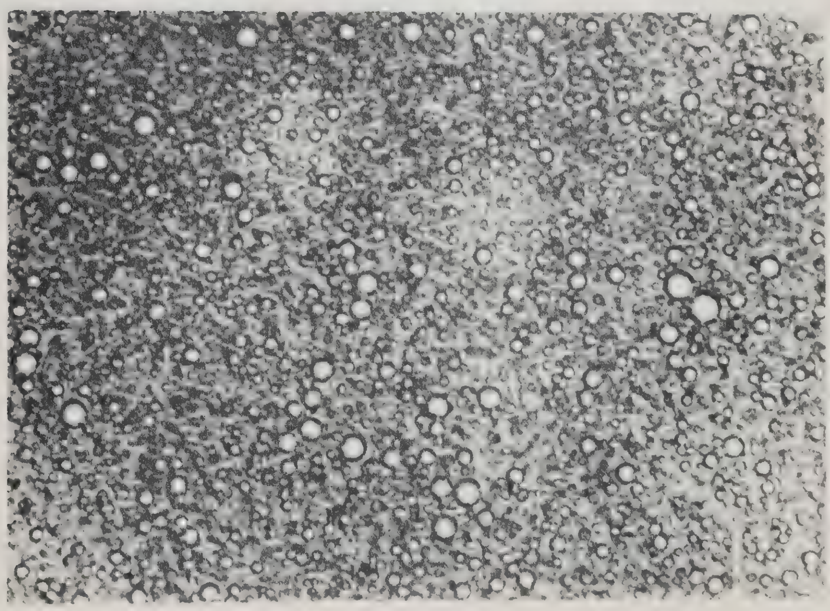


FIG. 12. Water-in-Oil Emulsion
Produced Run 220. Mag.(650x)

Wiborg[23] has also noted some emulsion formation in his experiments and stated two mechanisms which account for the increased recovery by emulsion formation:

1. the viscosity ratio between the displacing front and the displaced oil decreases since the viscosity of the emulsion approaches that of the external phase,
2. partial blocking of the paths of low resistance thereby leading to an improved pore volume sweep efficiency.

Generally it was found that the stability of the emulsion increased as the rate increased and as the permeability decreased. The emulsion produced from run 214 appeared to be the hardest to break. Extra varsol and extra centrifuging was needed to separate the phases. The emulsion produced during runs 219 and 212 was not difficult to break.

At low values of the scaling coefficient represented by runs 210, 211 and 213, the breakthrough recovery was constant. No emulsions were produced on these three runs. Emulsions were produced in all other runs and increased breakthrough recoveries were found on all these runs. Runs 214, 215, 216 and 217 have the lowest Ko_i values (see Table 2) averaging around 8 Darcy. These runs appear to place an upper bound on the breakthrough recoveries as shown by the curve in Figure 10. This curve will be

referred to as the 8 Darcy curve. Data points that fall below this line are for cores which had larger permeabilities.

If Table 2 is examined, a change in initial water saturations is noted. Runs 210 through 216 have initial water saturations averaging slightly greater than 9%. In runs 217 through 220 the initial water saturation was constant at a level near 7%.

Run 221 shows a very low water saturation of 5.4% and earlier in the discussion it was noted that this core had a high porosity value compared with the other cores. It was felt that an error had been made in the porosity determination which would also affect the saturations. The results of this run cannot be interpreted with confidence.

It should be noted that the recoveries for all runs that fall off the curve in Figure 10 have 7% initial water saturation present. Also those runs that fall off the curve have larger permeabilities than those that form the upper bound of the 8 Darcy curve in Figure 10.

Either one of the following two conditions might explain the scattering of results:

1. As the permeability increases the tortuosity of the flow paths decreases and the mixing action and shear stresses in the core are not as great and therefore a

less stable emulsion is formed.

2. The higher water saturation could promote better mixing since it has been shown that the connate water forms a bank in front of the injection water[24]. It is connate water which actually displaces the oil; therefore, if more connate water is available possibly a more stable emulsion might be formed.

More tests under more controlled conditions are needed before a decision can be made on which mechanism is responsible for the emulsion stability.

The data for the Wainwright crude oil were correlated in a Darcy Law cross-plot similar to that for the Dow Corning fluid. These results are presented in Figure 13. Here the rate of injection is plotted versus the pressure drop across the system. If Darcy's Law is valid this should yield a straight line with the slope equal to the conductance of the system. Each line represents a constant amount of water injected and therefore a constant saturation in the cores at the different rates studied.

From Figure 13 there appears to be a straight line at low displacement rates. At a rate of approximately 50 cc/hr the plots deviate from the straight line. This rate corresponds to the rate where emulsions were first noted in the system and the subsequent increase in recovery in Figure 10.

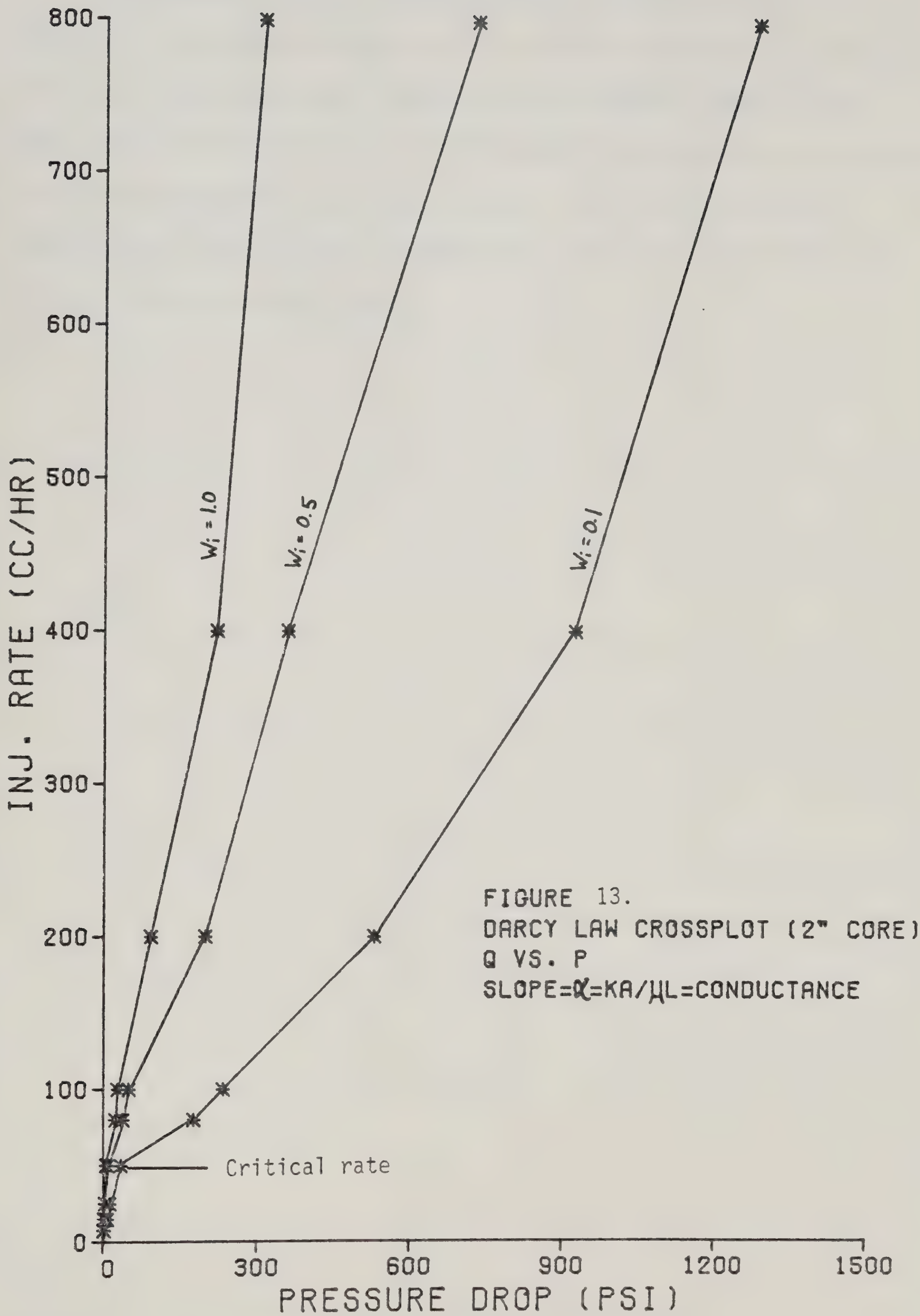


FIGURE 13.
DARCY LAW CROSSPLOT (2" CORE)
Q VS. P
SLOPE=α=KA/μL=CONDUCTANCE

The breaks in the relationships shown in Figure 13 show that the conductance of the system seems to be erratic after the emulsions are formed. This might support the fact that emulsions are being formed in-situ and are affecting the conductance in this manner. This variation in conductance could also indicate that the emulsions are not uniform from core to core.

VI. OBSERVATIONS AND CONCLUSIONS

Based on the results of this study the following observations and conclusions may be drawn:

1. An increase in flooding velocity for tests on cores containing a synthetic Dow Corning fluid caused a decrease in breakthrough recovery of about 10%.
2. A region of apparent non-Darcy flow was found in the Dow Corning system at injection rates greater than approximately 265 cc/hr. However, this did not explain the decrease in recovery noted with the Dow Corning fluid since most of the decrease was observed at lower rates.
3. Emulsion formation appears to be an extremely effective recovery mechanism. A five-fold increase in breakthrough recovery was noted for the Wainwright crude oil over the range of rates investigated.
4. The stability of the emulsions formed appeared to be sensitive to either the permeability of the system or the amount of initial water saturation or both.
5. The Dow Corning fluid initiated a wettability reversal in one core when the saturated core was aged for a period of 15 days.

6. Relative permeabilities calculated by the external drive technique appear to be unreliable. Wide fluctuations in the calculated data appear even when smoothing of the input data was performed.

VII. RECOMMENDATIONS

* The sand used for displacement tests should either be sorted to narrower grain size range or a number of shipments thoroughly mixed so that the grain size for the entire series is more uniform. The sandpack properties should then be reproducible.
* The permeability should be carefully controlled and a complete series of runs obtained for a number of different permeabilities to ascertain the nature of the sensitivity of emulsion formation to permeability.
* The idea of injecting a slug of emulsion and then waterflooding should be examined to improve sweep efficiencies at lower more reasonable rates.
* Tests should be initiated on sandpacks that have more realistic field permeabilities to see what rates must be exceeded to produce emulsions under these conditions.
* A number of closely controlled tests with a number of permeabilities and a complete range of rates may lead to a correlation for predicting this "critical" rate where non-Darcy flow starts.
* More detail must be obtained in the region where the flow changes to non-Darcy to determine if this is a transition region or a sharp break.

* The idea that wetting conditions cannot manifest themselves at high rates deserves to be examined more closely. Perhaps a complete series on similar systems except that one be oil-wet and one be water-wet would provide some clues.

NOMENCLATURE

A	=	$\sqrt{(M-1)B\ Sw_m} + B$
B	=	$1 - So_r - Sw_m$
C	=	CHOUKE constant (dimensionless)
D	=	diameter of tube (cm)
f_o	=	fraction of oil flowing from system
f_w	=	fraction of water flowing from system
g	=	gravitational constant
I	=	$\frac{LV\mu_w}{\sigma\sqrt{K}}$, dimensionless group
I_R	=	relative injectivity
I.O.I.P.	=	initial oil in place
K	=	absolute permeability (darcy)
K_o	=	effective permeability to oil (darcy)
K_w	=	effective permeability to water (darcy)
K_{ro}	=	relative permeability to oil
K_{rw}	=	relative permeability to water

L = length of tube

L_t = $\frac{\sigma \cos \theta \sqrt{K/\phi}}{LV\mu_w}$, dimensionless group

M = viscosity ratio

Np = cumulative oil production (cc)

Np_b = recovery at water breakthrough (cc)

Pc = capillary pressure (atm)

Po = pressure in oil phase (atm)

Pw = pressure in water phase (atm)

Q = injection rate (cc/hr)

q_o = oil flow rate (cc/sec)

q_w = water flow rate (cc/sec)

S_1 = inlet saturation in terms of wetting phase

S_2 = outlet saturation in terms of wetting phase

So = oil saturation

So_r = residual oil saturation

Sw = water saturation

Sw_f = water saturation at flood front

Sw_i = initial water saturation

Sw_m = immobile water saturation

$V=u$ = total flow rate per unit cross sectional area, cm/sec

W_i = pore volumes injected, dimensionless

λ_{cr} = critical wavelength (cm)

λ_m = average wavelength (cm)

μ_o = viscosity of oil (poise)

μ_w = viscosity of water (poise)

σ = interfacial tension (dynes/cm)

θ = wetting angle

ϕ = porosity

ρ_o = density of oil (gm/cc)

ρ_w = density of water (gm/cc)

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APPENDIX A

FLUID PROPERTIES

FLUIDS:

DOW CORNING 200 @ 74°F

Interfacial tension - 34.04 dynes/cm

density - 0.9691 gm/cc

WAINWRIGHT CRUDE OIL @ 74°F

Interfacial tension - 26.97 dynes/cm

density - 0.9974 gm/cc

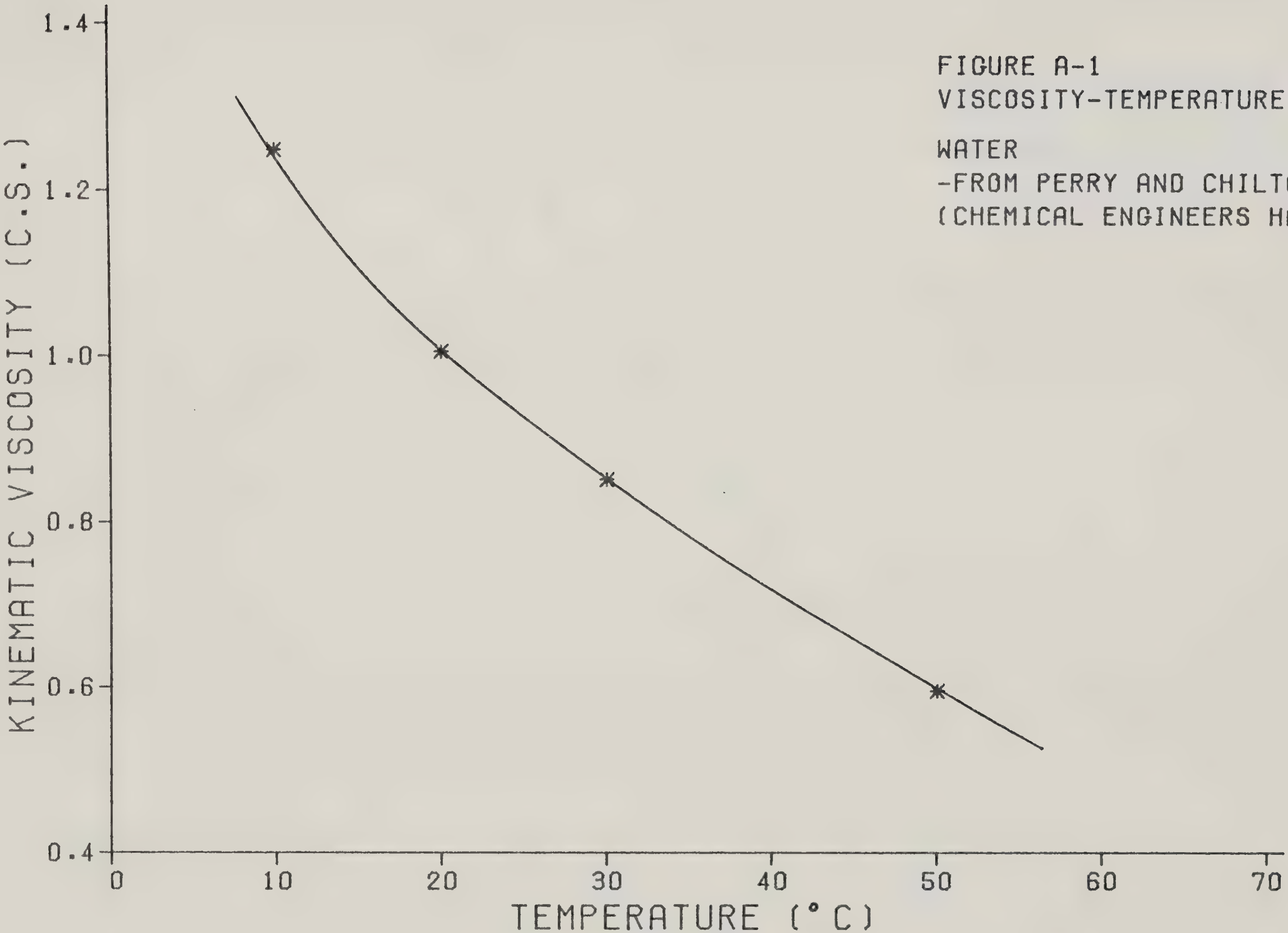


FIGURE A-1
VISCOSITY-TEMPERATURE PROFILE

WATER
-FROM PERRY AND CHILTON
(CHEMICAL ENGINEERS HANDBOOK)

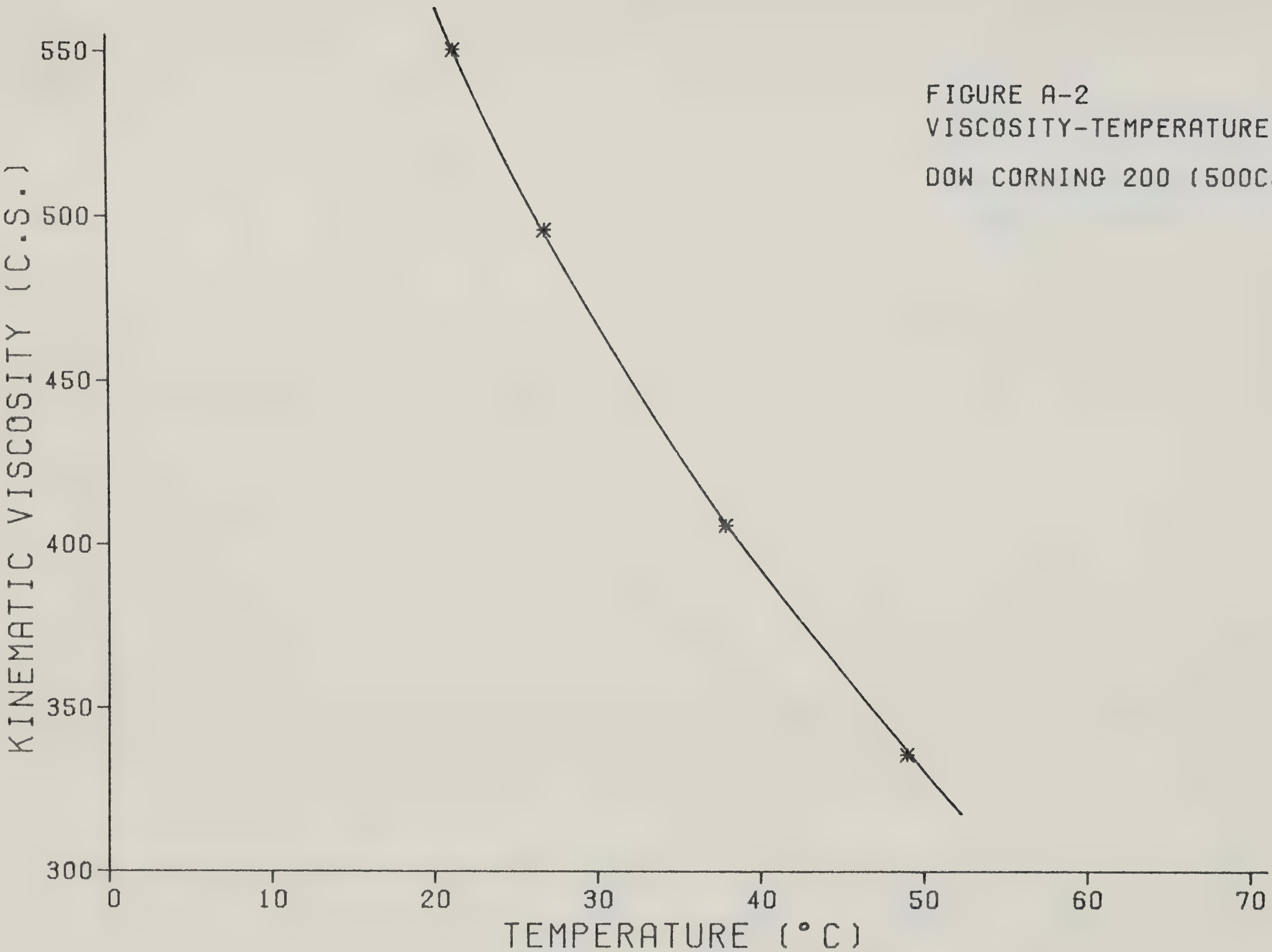


FIGURE A-2
VISCOSITY-TEMPERATURE PROFILE
DOW CORNING 200 (500CS)

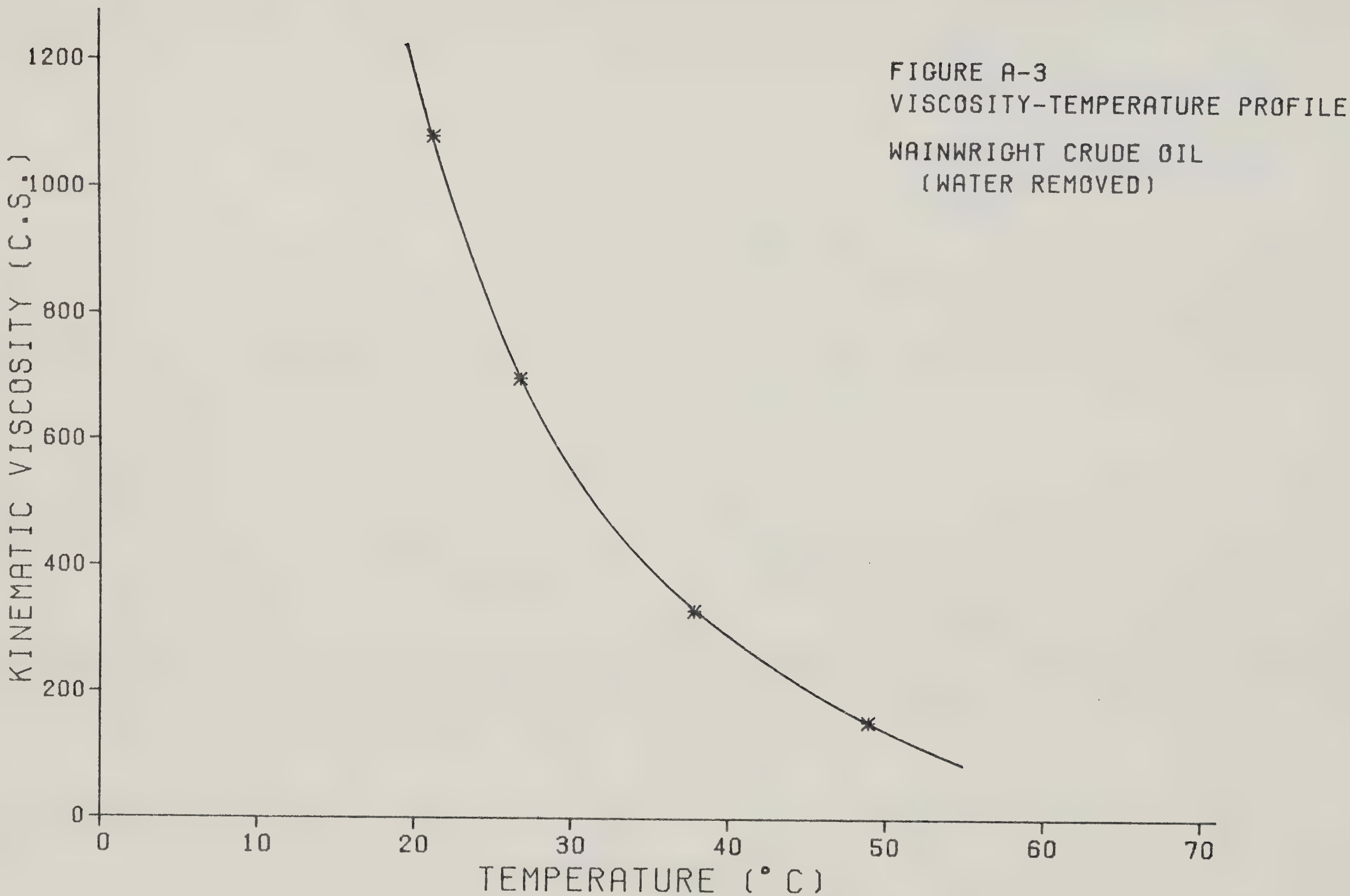


FIGURE A-3
VISCOSITY-TEMPERATURE PROFILE
WAINWRIGHT CRUDE OIL
(WATER REMOVED)
KINEMATIC VISCOSITY (C.S.)
1200
1000
800
600
400
200
0
0
10
20
30
40
50
60
70
TEMPERATURE (° C)

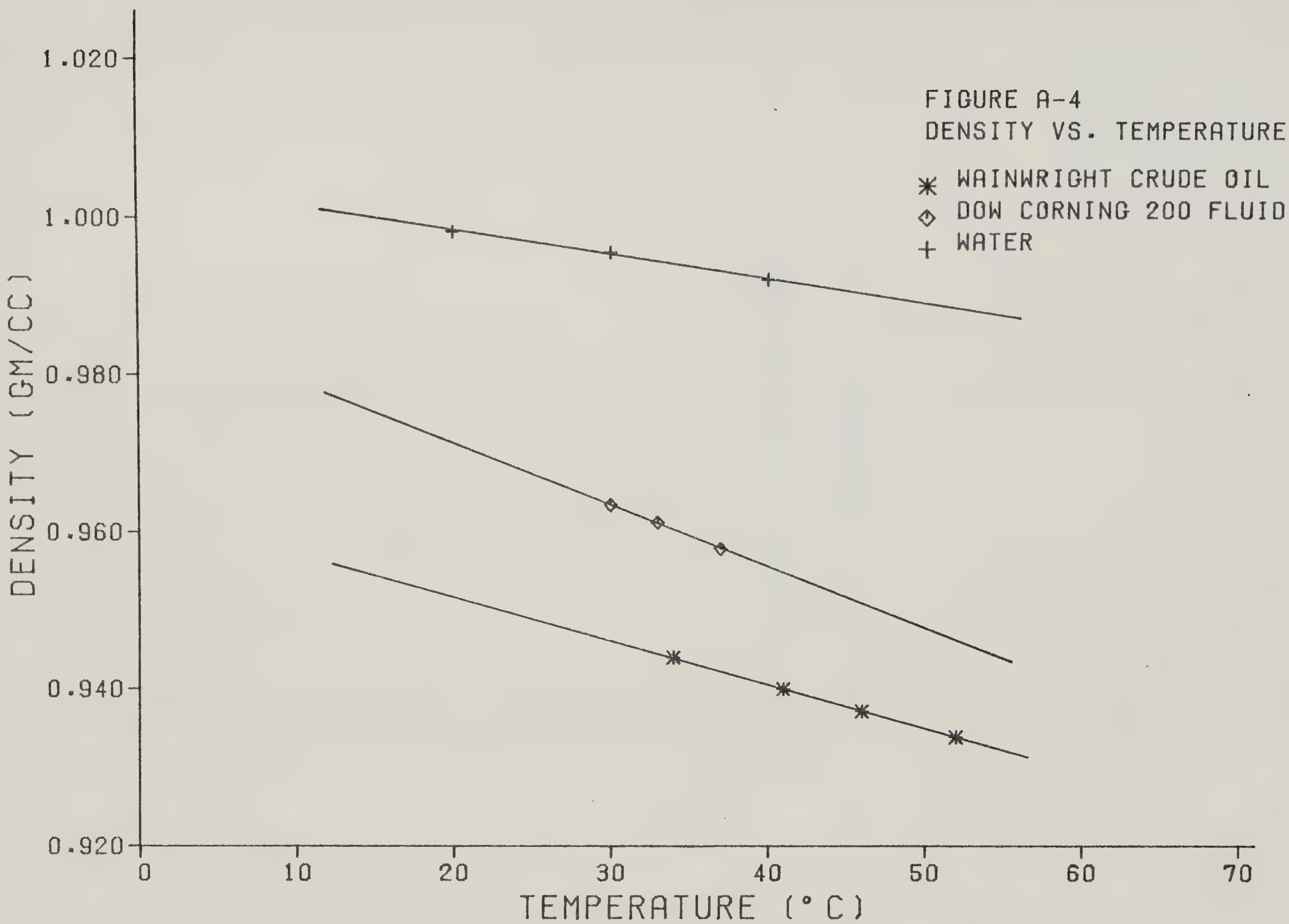


FIGURE A-4
DENSITY VS. TEMPERATURE
WAINWRIGHT CRUDE OIL
DOW CORNING 200 FLUID
WATER
DENSITY (GM/CC)
1.020
1.000
0.980
0.960
0.940
0.920
0
10
20
30
40
50
60
70
TEMPERATURE (°C)

APPENDIX B

RECOVERY HISTORY CURVES

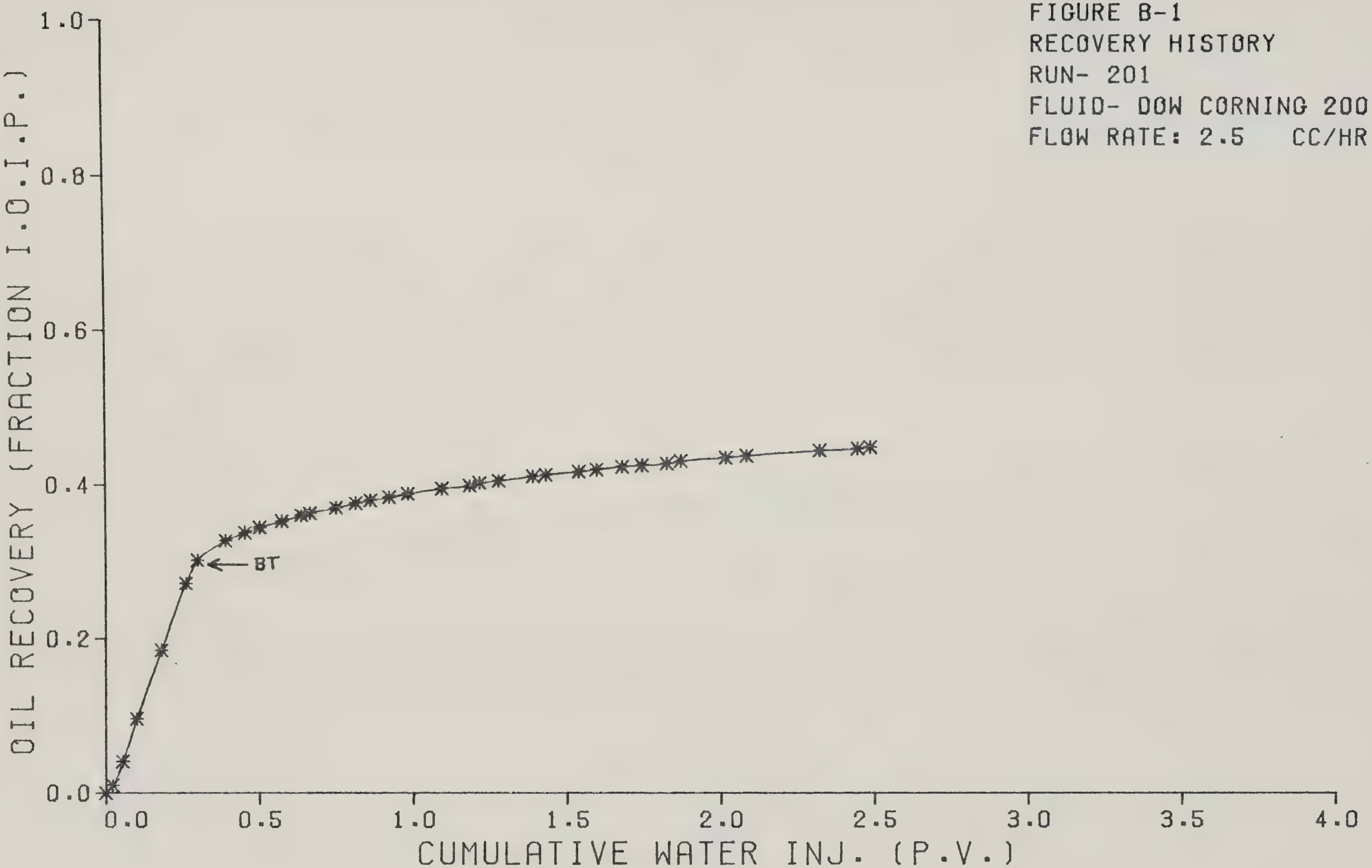


FIGURE B-1
RECOVERY HISTORY
RUN- 201
FLUID- DOW CORNING 200
FLOW RATE: 2.5 CC/HR

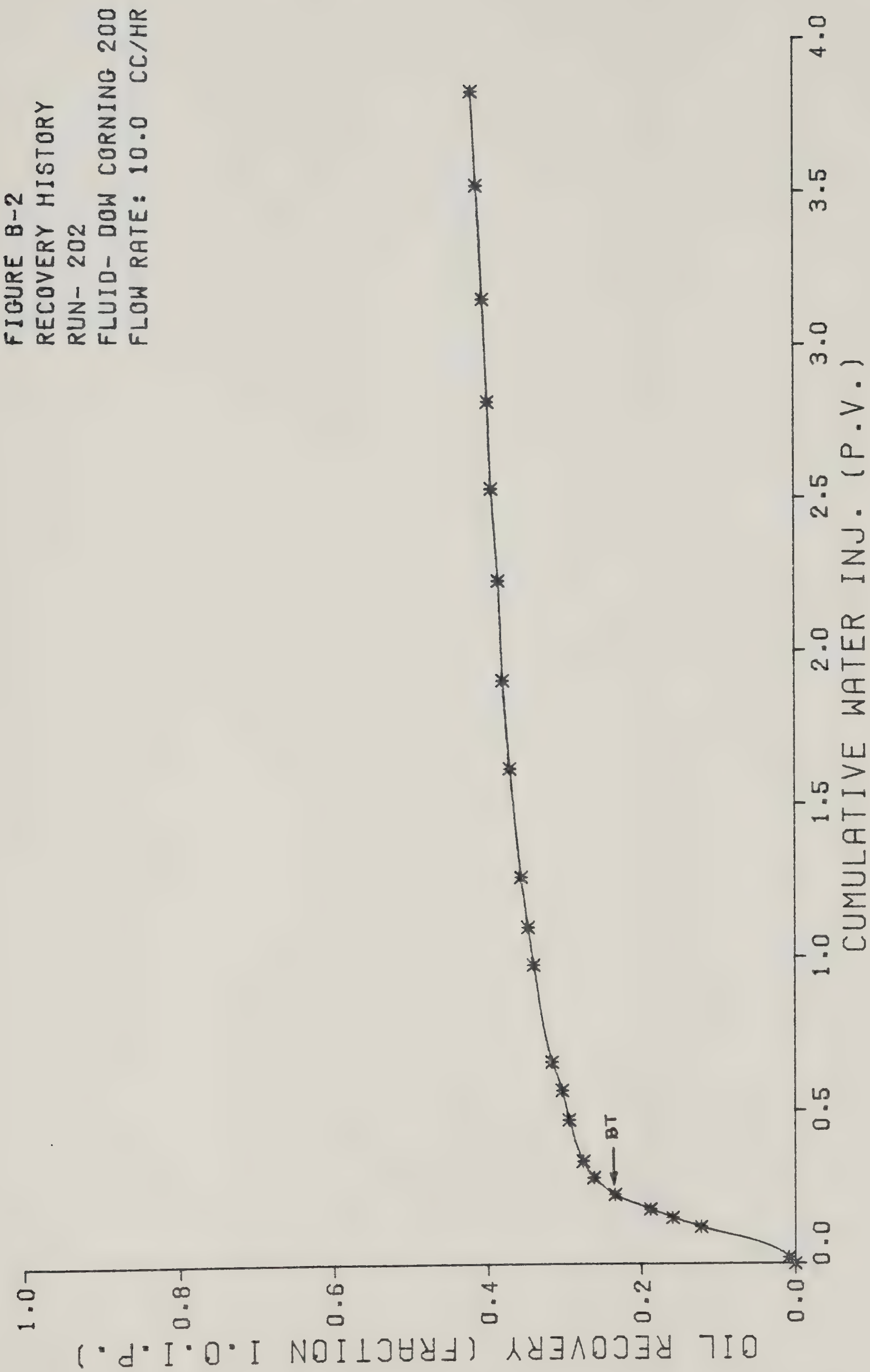
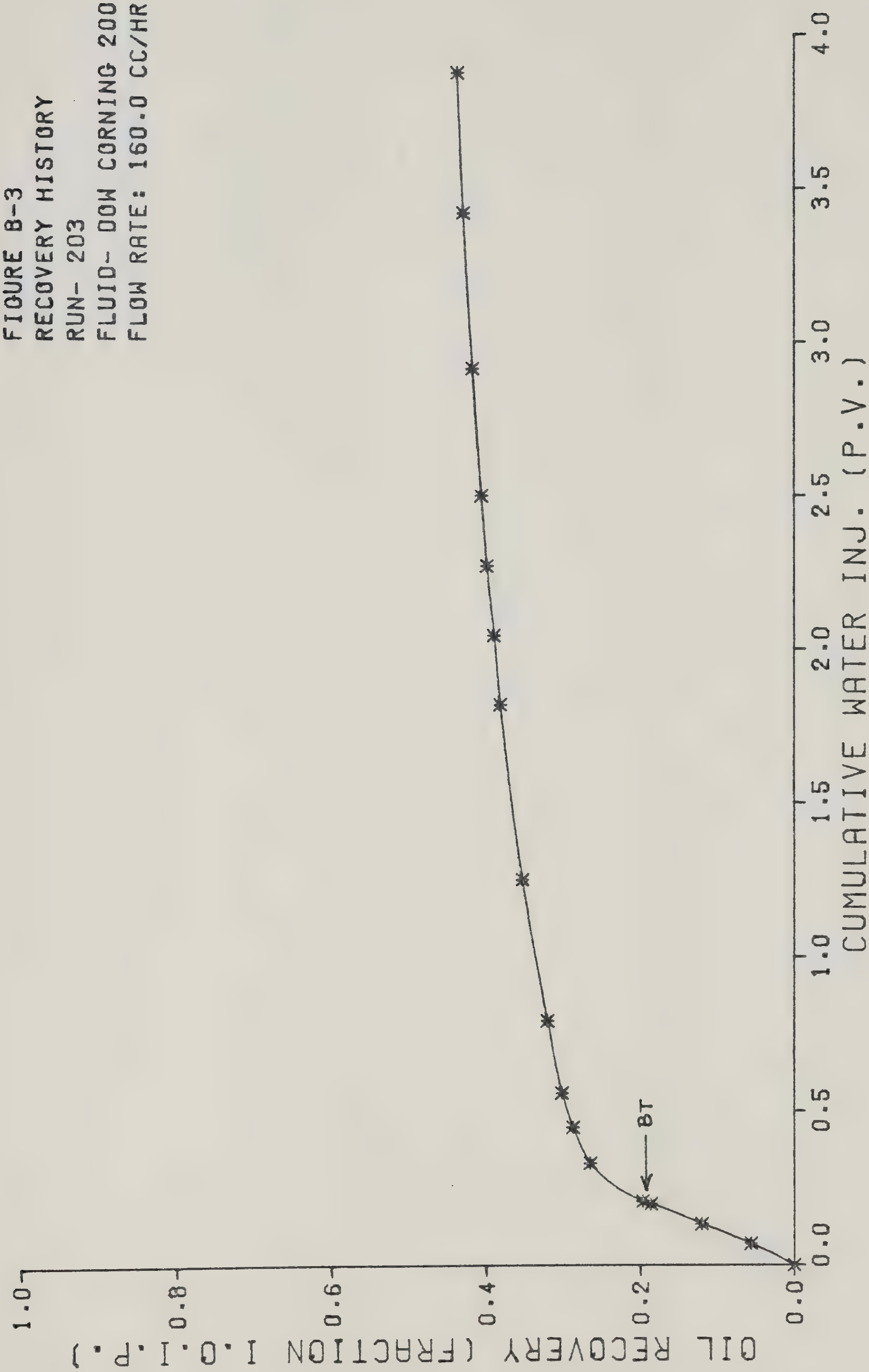


FIGURE B-2
RECOVERY HISTORY
RUN- 202
FLUID- DOW CORNING 200
FLOW RATE: 10.0 CC/HR
BT
OIL RECOVERY (FRACTION I.O.I.P.)
CUMULATIVE WATER INJ. (P.V.)
0.0
0.2
0.4
0.6
0.8
1.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0

FIGURE B-3
RECOVERY HISTORY
RUN- 203
FLUID- DOW CORNING 200
FLOW RATE: 160.0 CC/HR



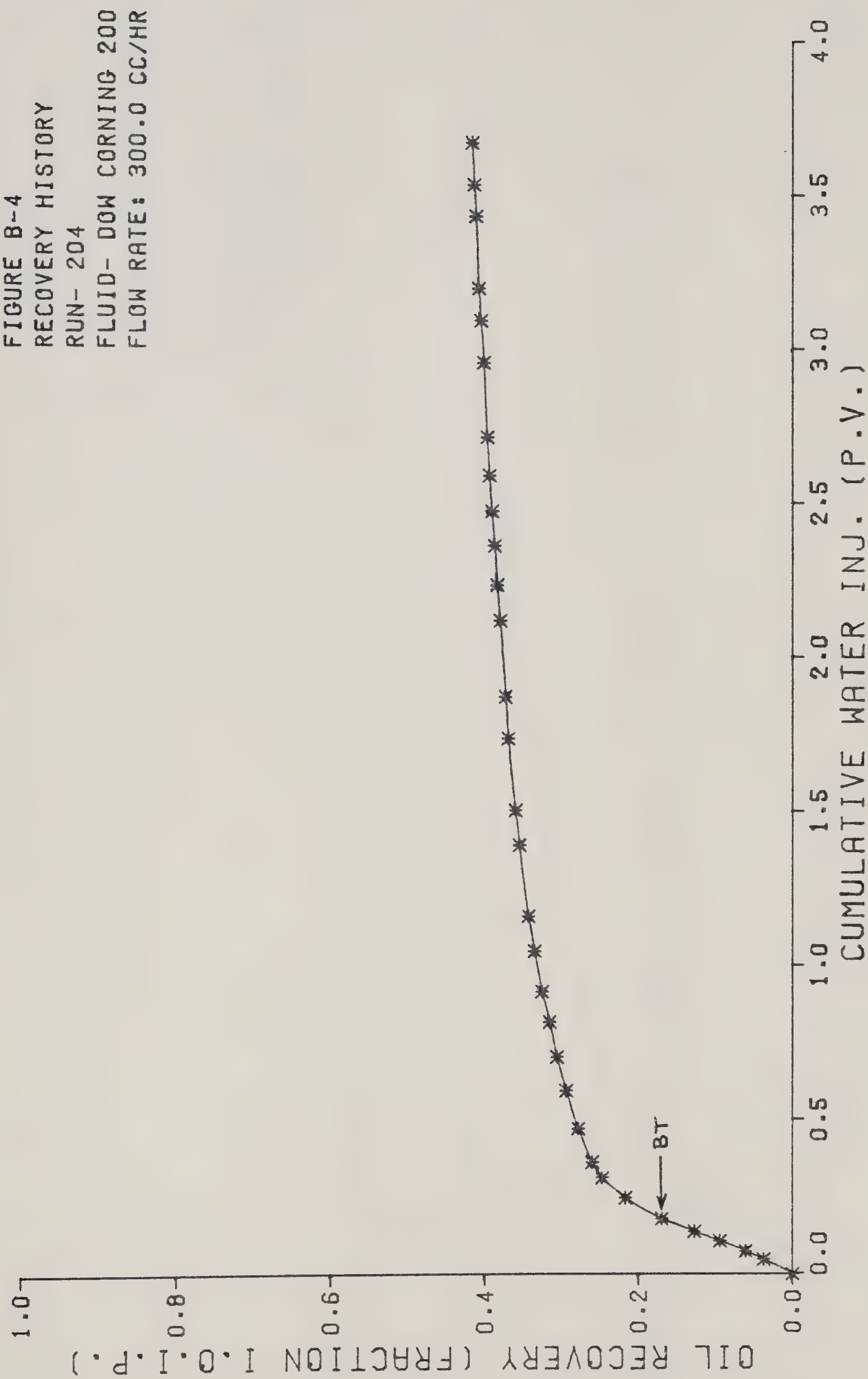


FIGURE B-4
RECOVERY HISTORY
RUN- 204
FLUID- DOW CORNING 200
FLOW RATE: 300.0 CC/HR
BT
OIL RECOVERY (FRACTION I.O.I.P.)
0.0
0.2
0.4
0.6
0.8
1.0
CUMULATIVE WATER INJ. (P.V.)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0

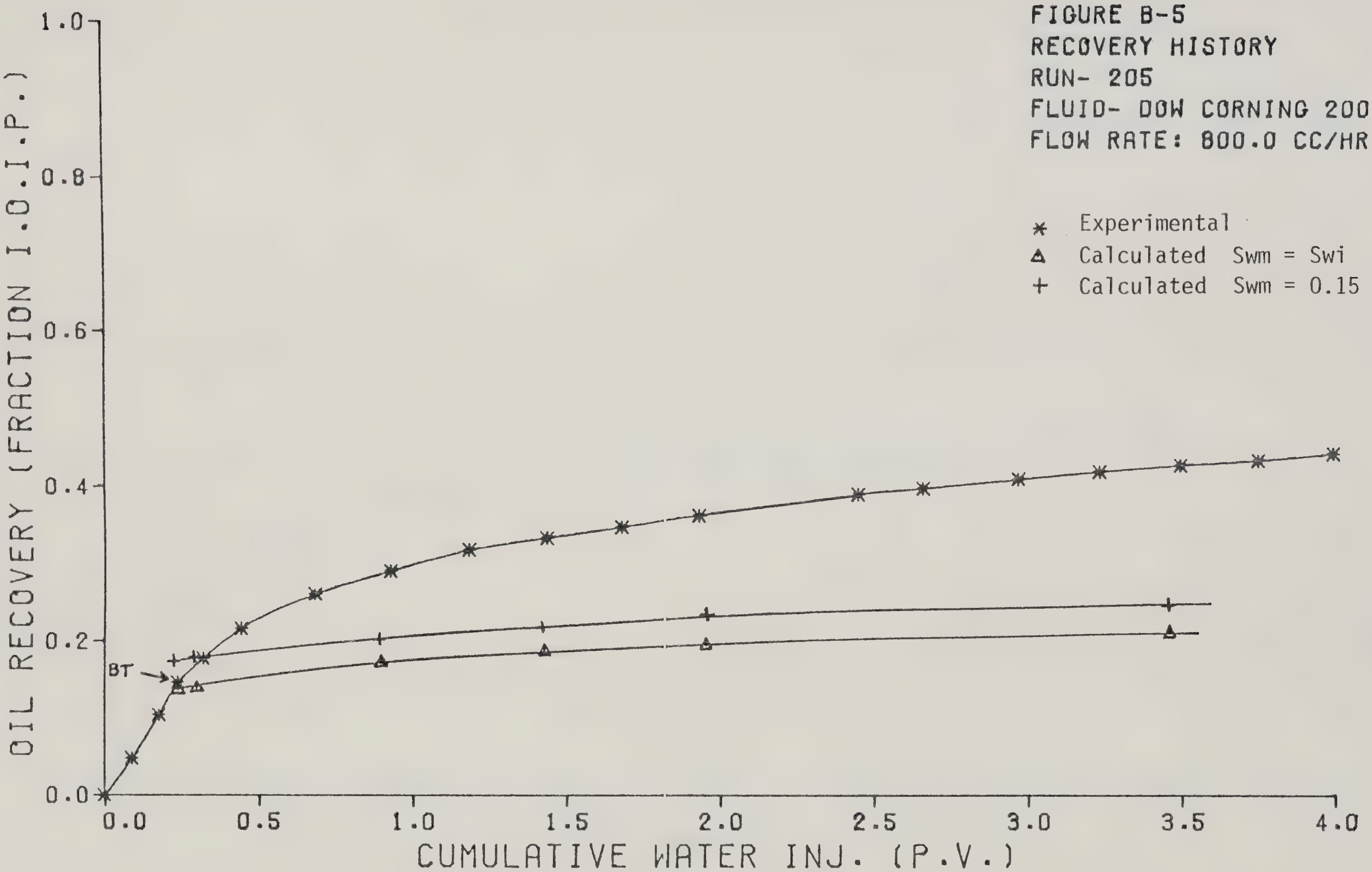


FIGURE B-5
RECOVERY HISTORY
RUN- 205
FLUID- DOW CORNING 200
FLOW RATE: 800.0 CC/HR

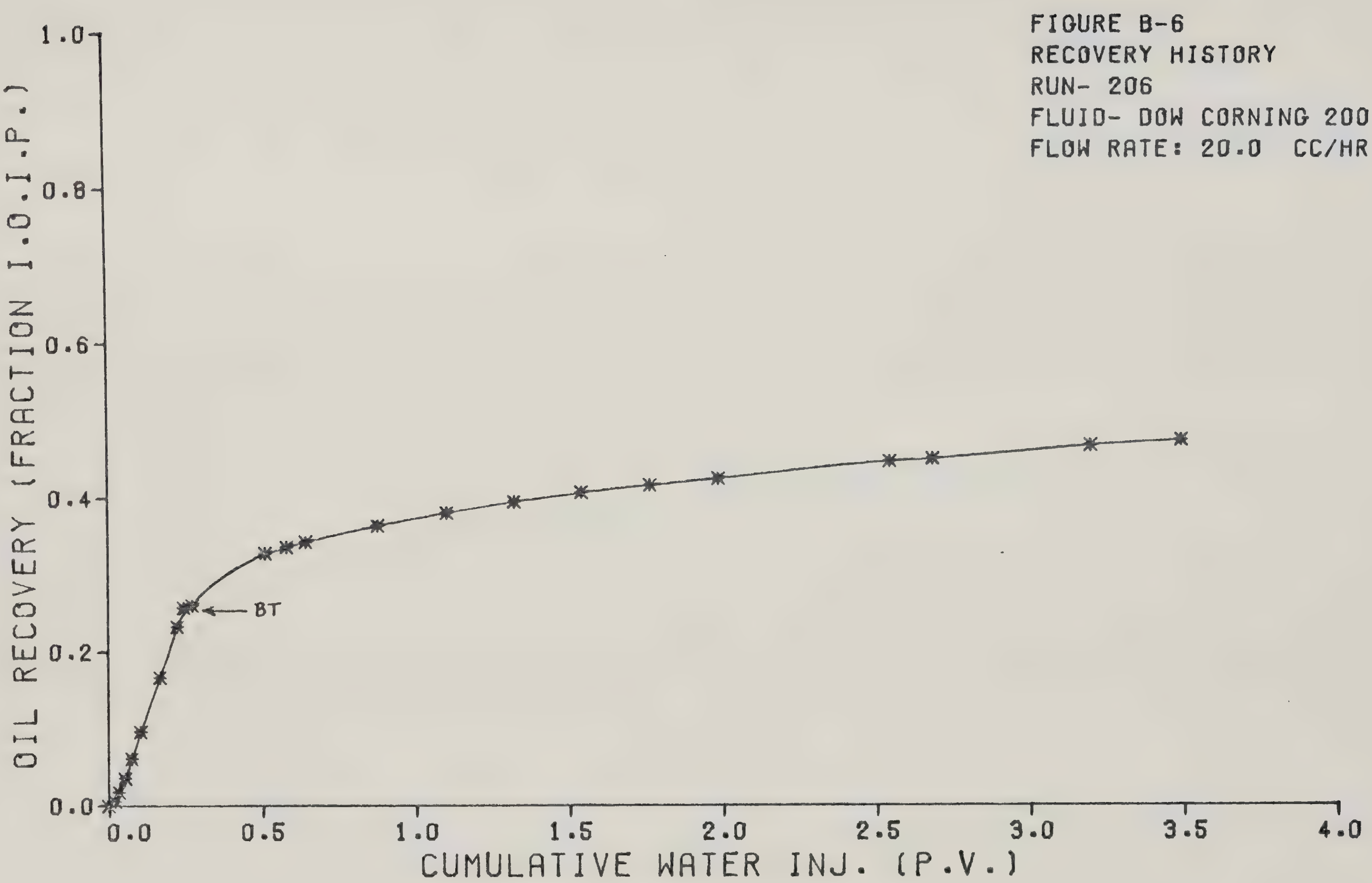
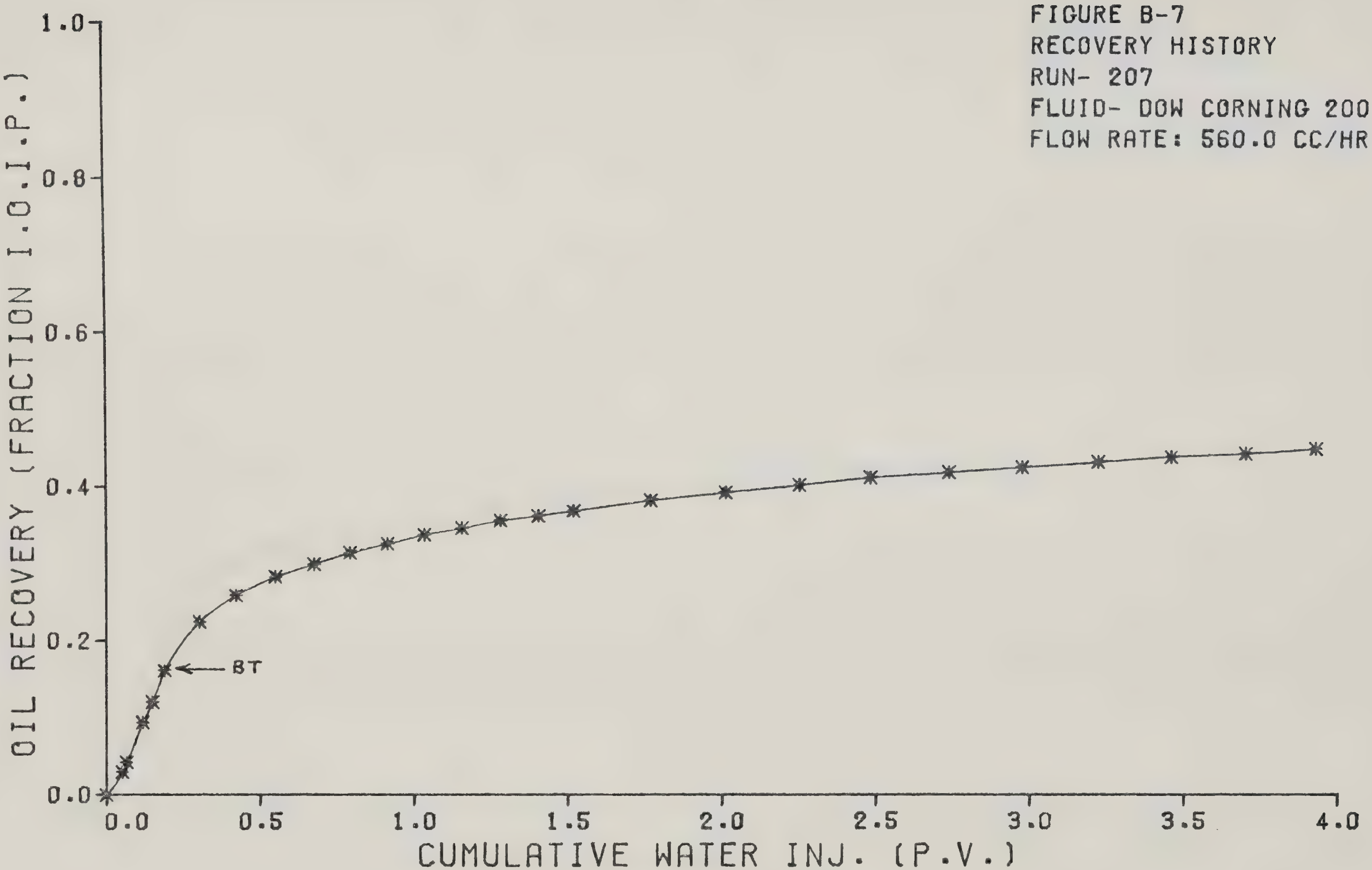


FIGURE B-6
RECOVERY HISTORY
RUN- 206
FLUID- DOW CORNING 200
FLOW RATE: 20.0 CC/HR
BT
OIL RECOVERY (FRACTION I.O.I.P.)
0.0
0.2
0.4
0.6
0.8
1.0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
CUMULATIVE WATER INJ. (P.V.)

FIGURE B-7
RECOVERY HISTORY
RUN- 207
FLUID- DOW CORNING 200
FLOW RATE: 560.0 CC/HR



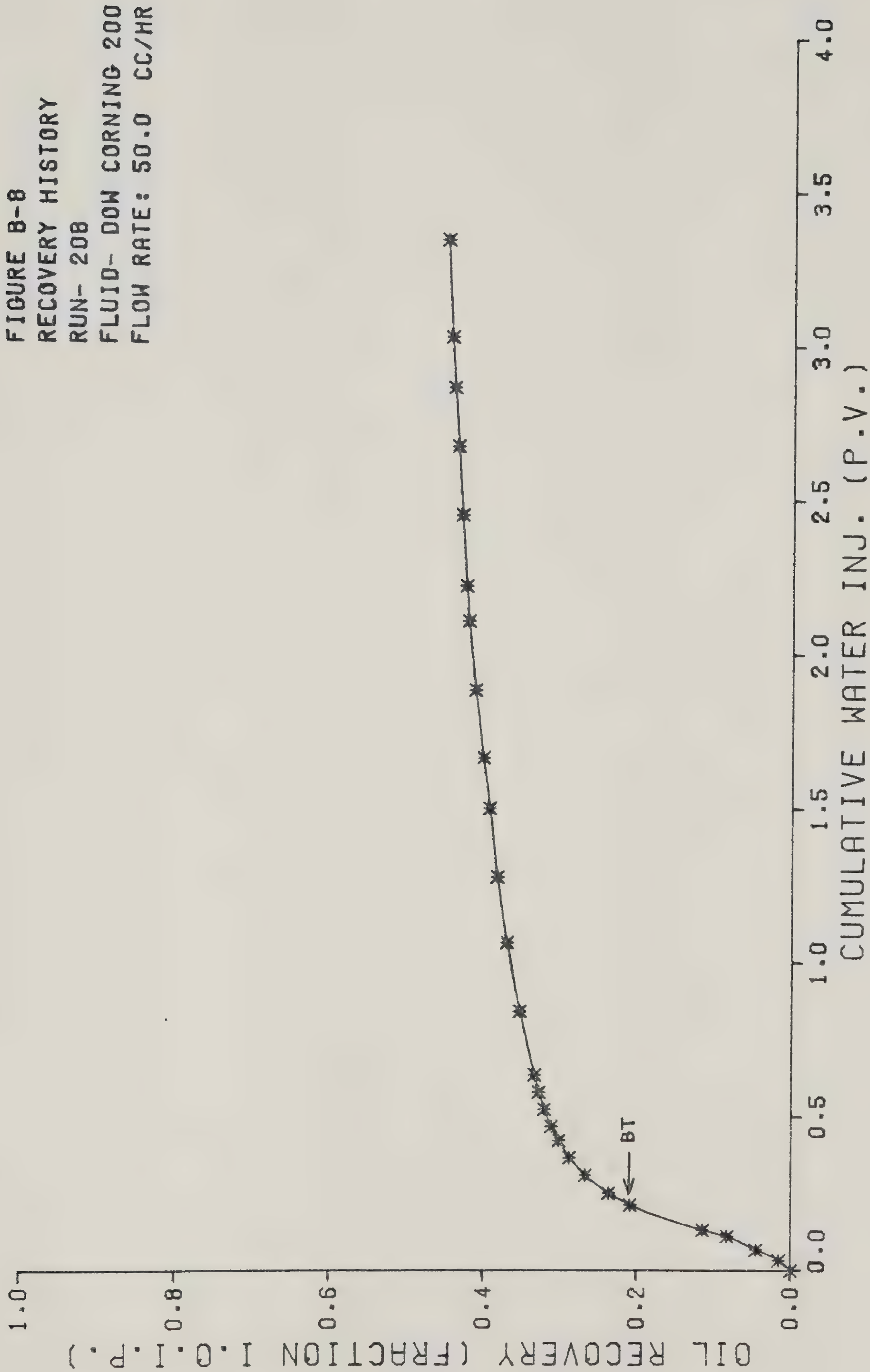


FIGURE B-8
RECOVERY HISTORY
RUN- 20B
FLUID- DOW CORNING 200
FLOW RATE: 50.0 CC/HR
BT
OIL RECOVERY (FRACTION I.O.I.P.)
0.0
0.2
0.4
0.6
0.8
1.0
CUMULATIVE WATER INJ. (P.V.)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0

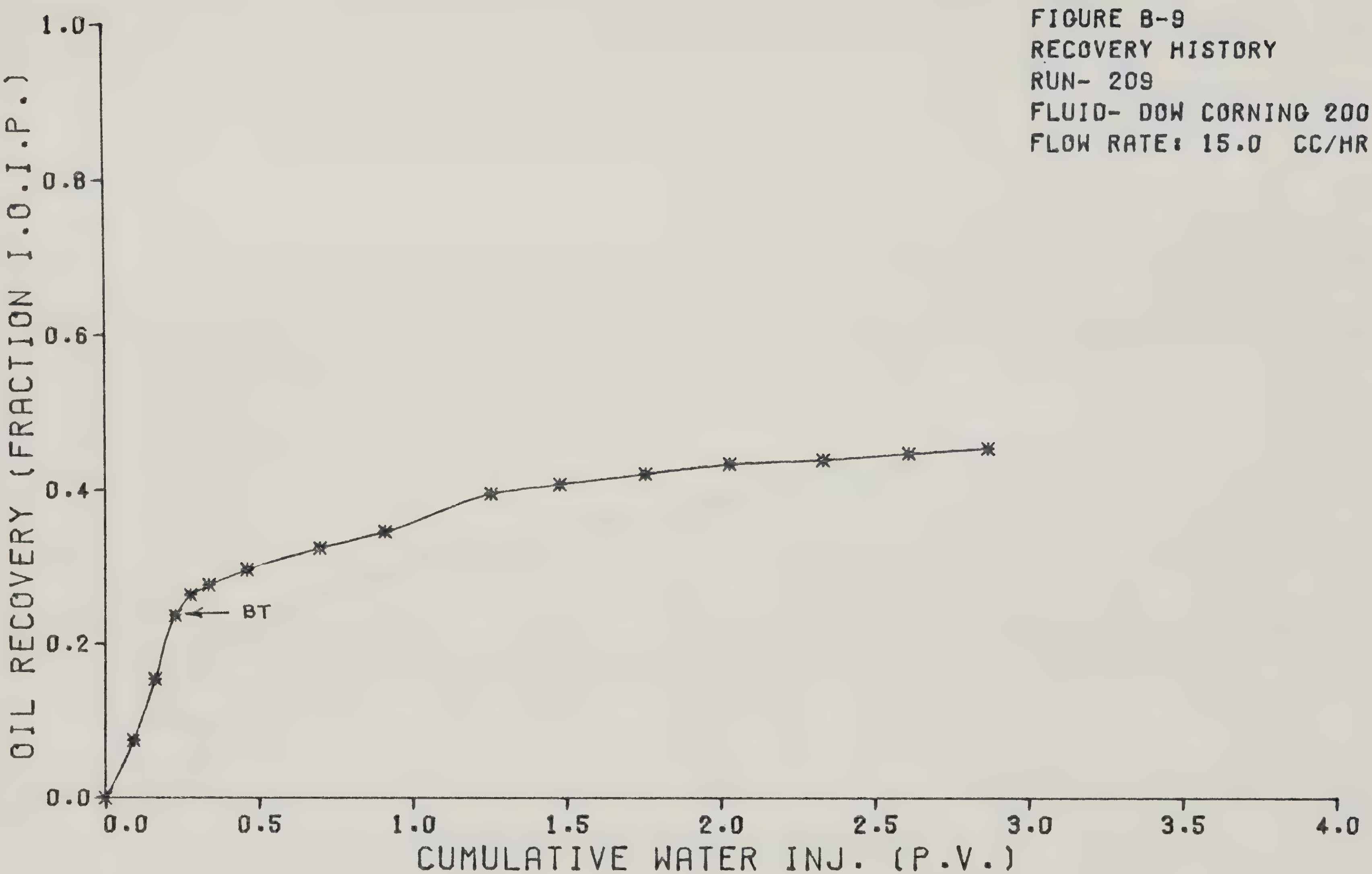


FIGURE B-9
RECOVERY HISTORY
RUN- 209
FLUID- DOW CORNING 200
FLOW RATE: 15.0 CC/HR
OIL RECOVERY (FRACTION I.O.I.P.)
CUMULATIVE WATER INJ. (P.V.)
BT
1.0
0.8
0.6
0.4
0.2
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0

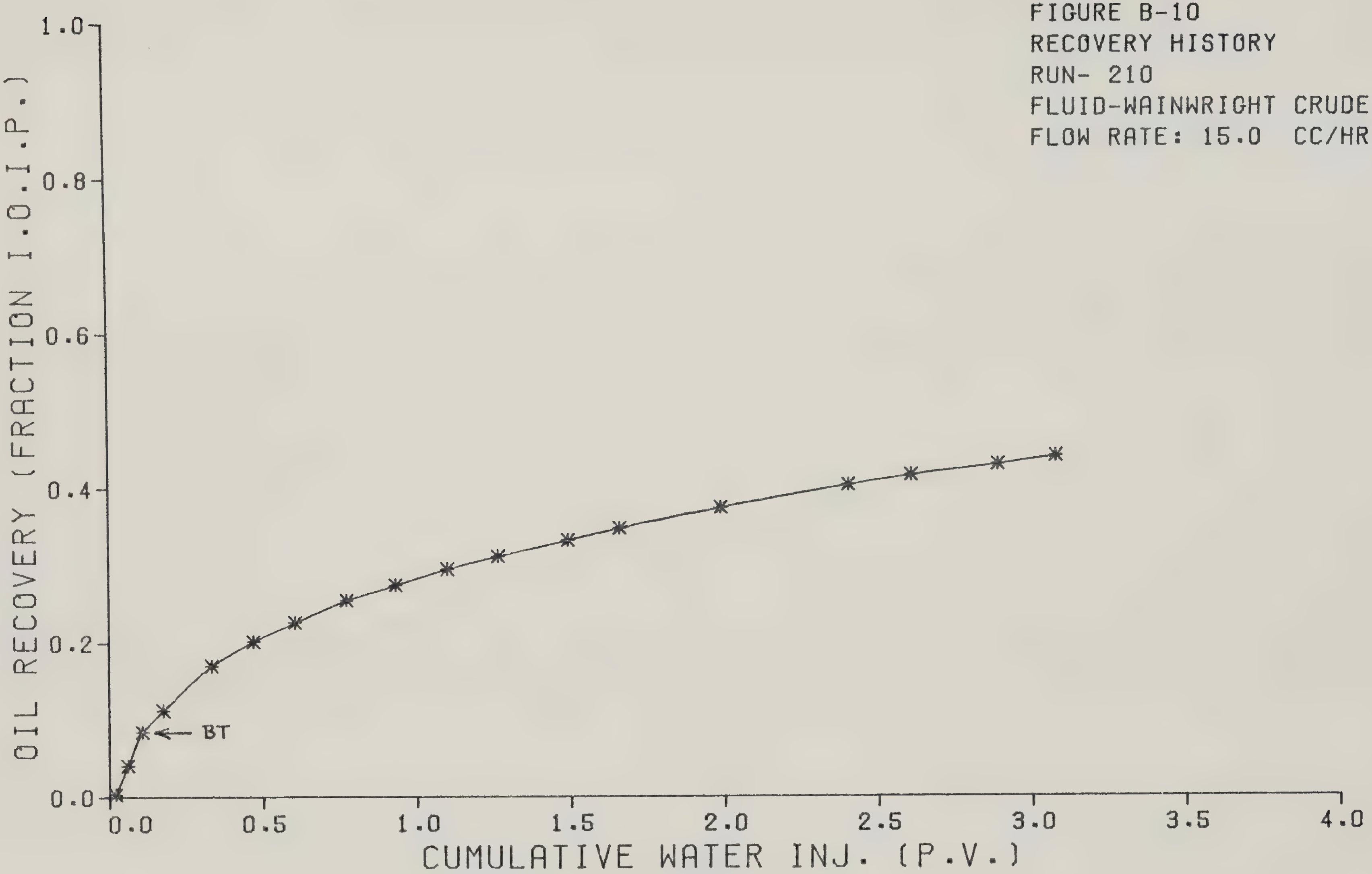


FIGURE B-10
RECOVERY HISTORY
RUN- 210
FLUID-WAINWRIGHT CRUDE
FLOW RATE: 15.0 CC/HR

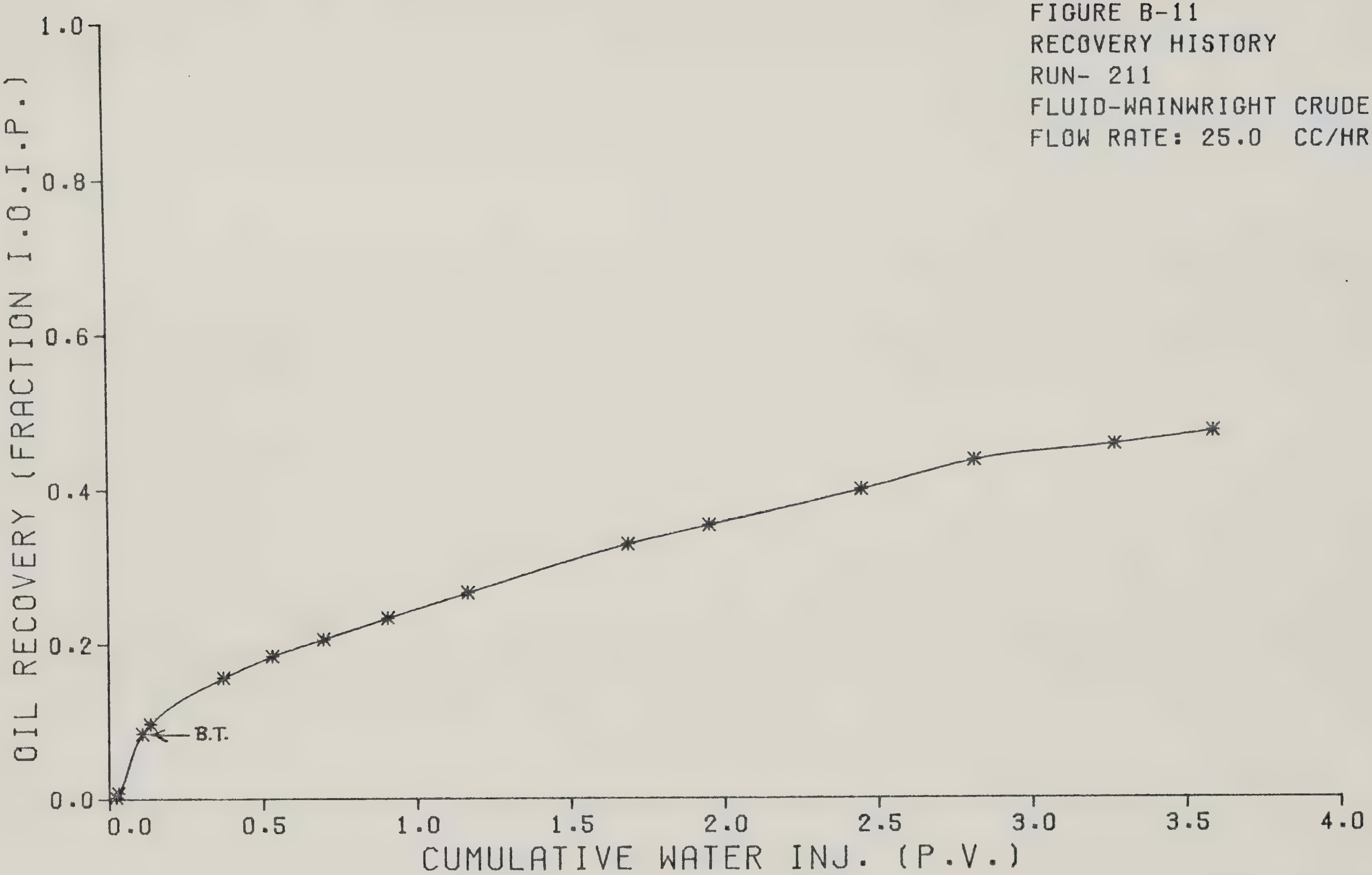


FIGURE B-11
RECOVERY HISTORY
RUN- 211
FLUID-WAINWRIGHT CRUDE
FLOW RATE: 25.0 CC/HR

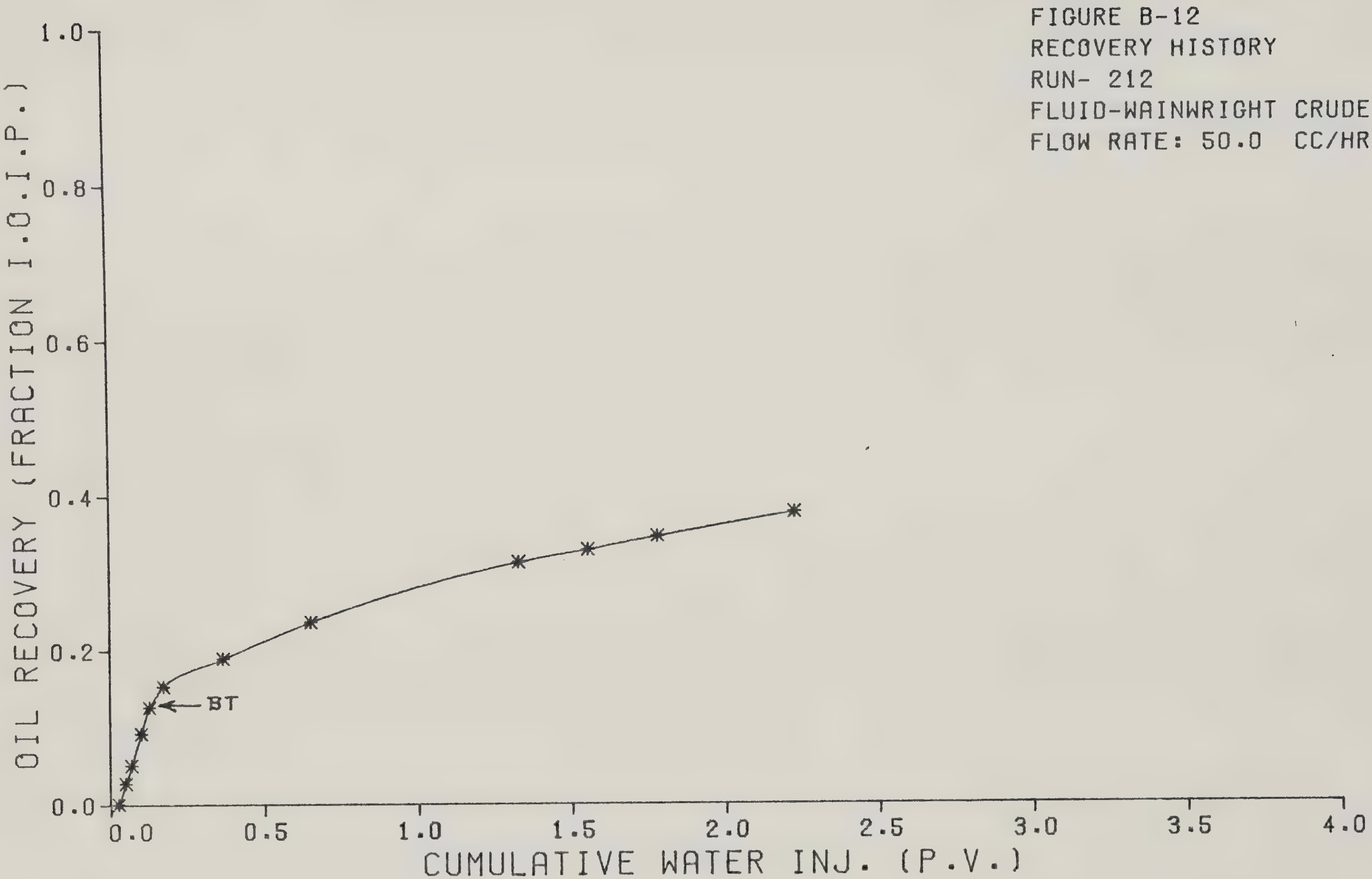


FIGURE B-12
RECOVERY HISTORY
RUN- 212
FLUID-WAINWRIGHT CRUDE
FLOW RATE: 50.0 CC/HR
OIL RECOVERY (FRACTION I.O.I.P.)
1.0
0.8
0.6
0.4
0.2
0.0
BT
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
CUMULATIVE WATER INJ. (P.V.)

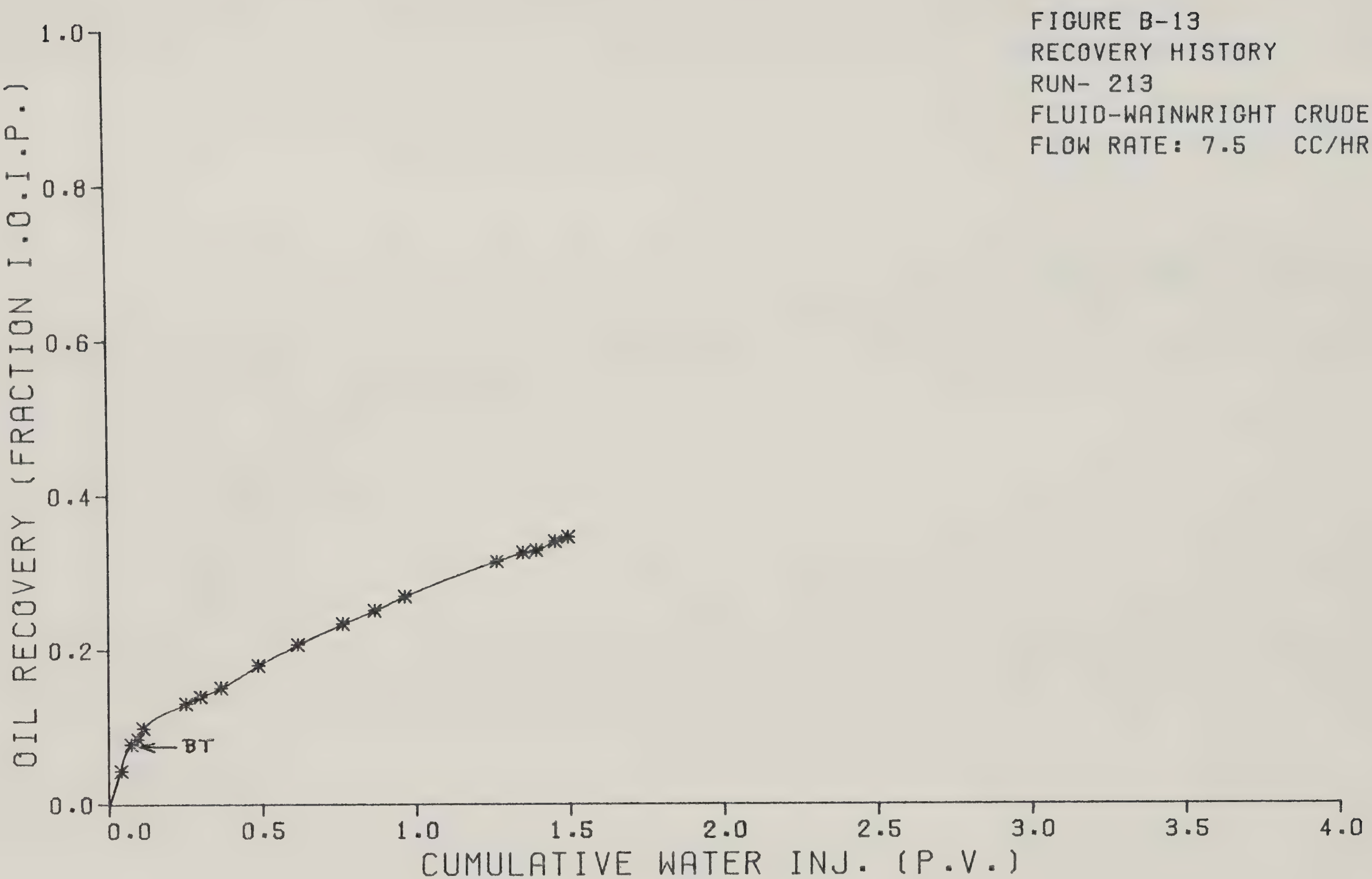


FIGURE B-13
RECOVERY HISTORY
RUN- 213
FLUID-WAINWRIGHT CRUDE
FLOW RATE: 7.5 CC/HR

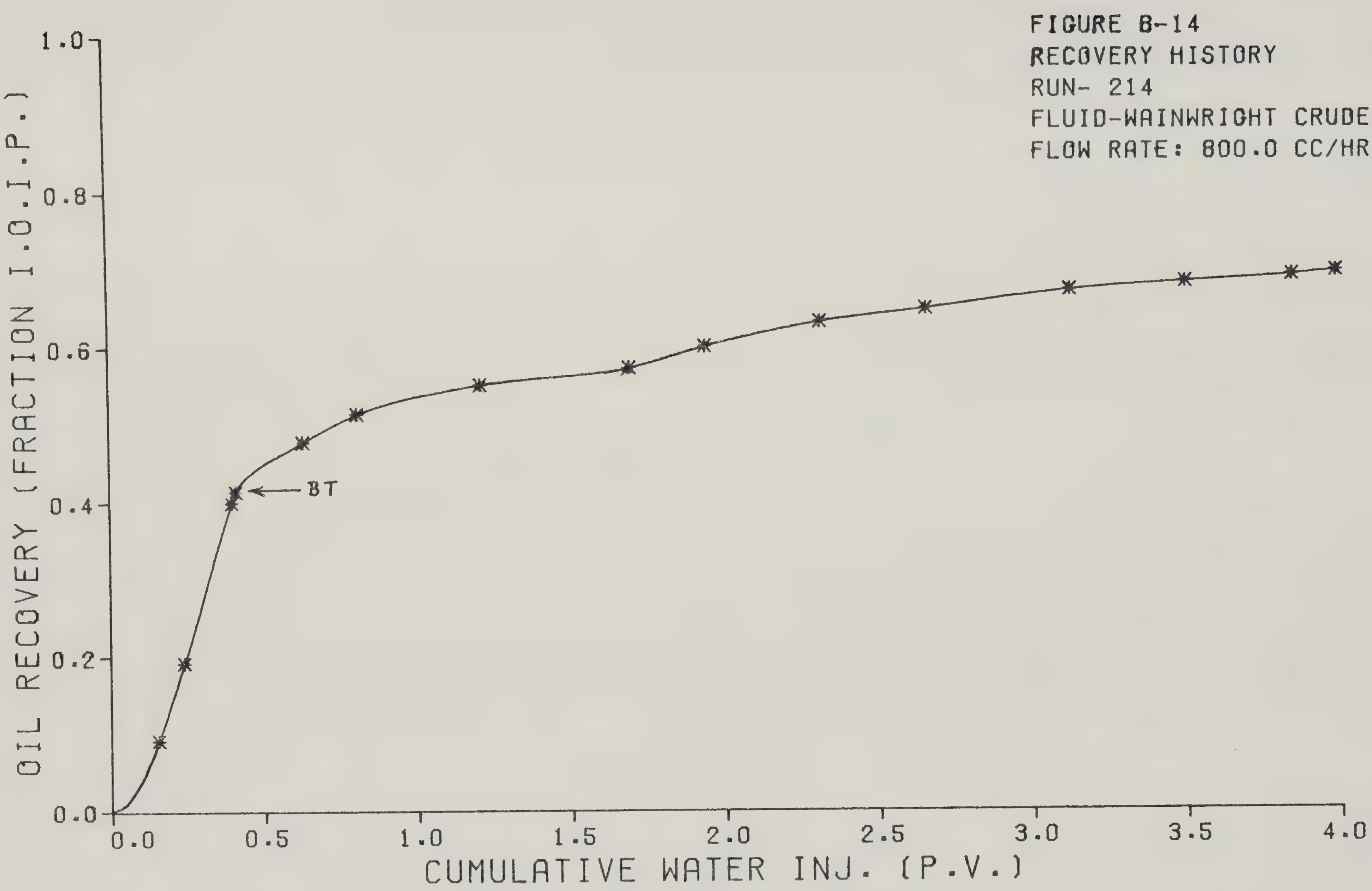


FIGURE B-14
RECOVERY HISTORY
RUN- 214
FLUID-WAINWRIGHT CRUDE
FLOW RATE: 800.0 CC/HR
OIL RECOVERY (FRACTION I.O.I.P.)
1.0
0.8
0.6
0.4
0.2
0.0
BT
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
CUMULATIVE WATER INJ. (P.V.)

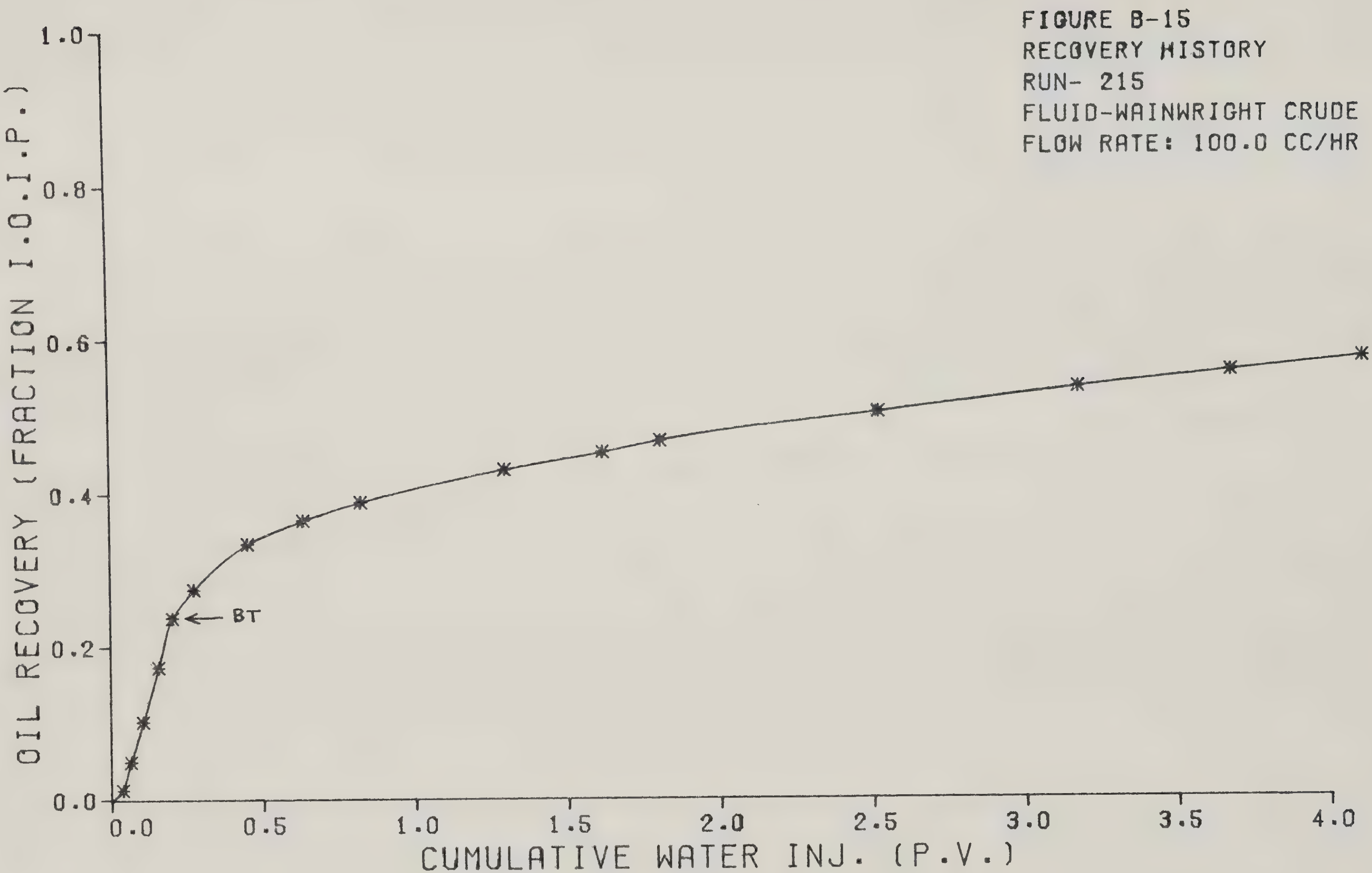


FIGURE B-15
RECOVERY HISTORY
RUN- 215
FLUID-WAINWRIGHT CRUDE
FLOW RATE: 100.0 CC/HR
BT
OIL RECOVERY (FRACTION I.O.I.P.)
CUMULATIVE WATER INJ. (P.V.)
0.0
0.2
0.4
0.6
0.8
1.0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0

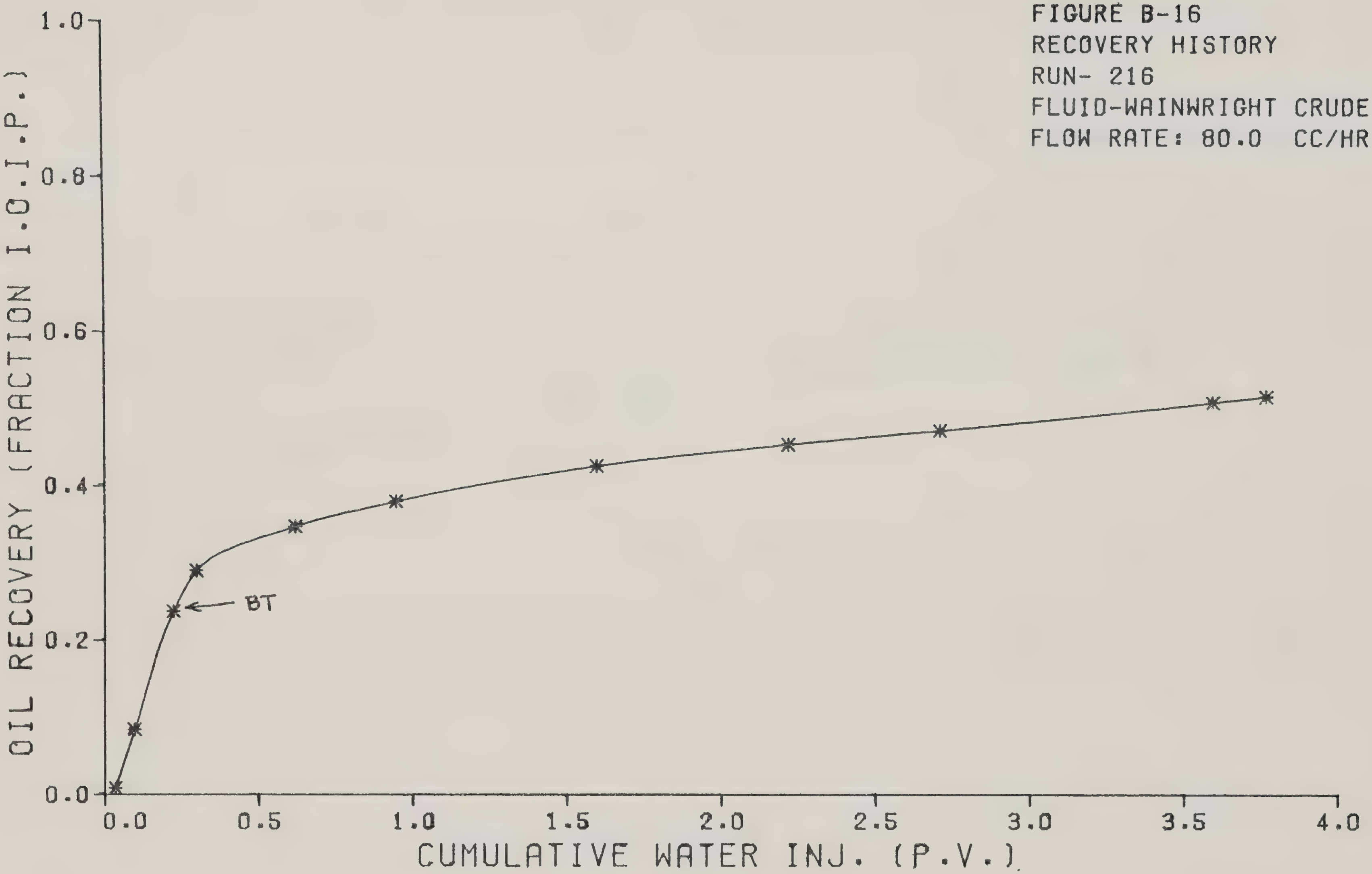


FIGURE B-16
RECOVERY HISTORY
RUN- 216
FLUID-WAINWRIGHT CRUDE
FLOW RATE: 80.0 CC/HR

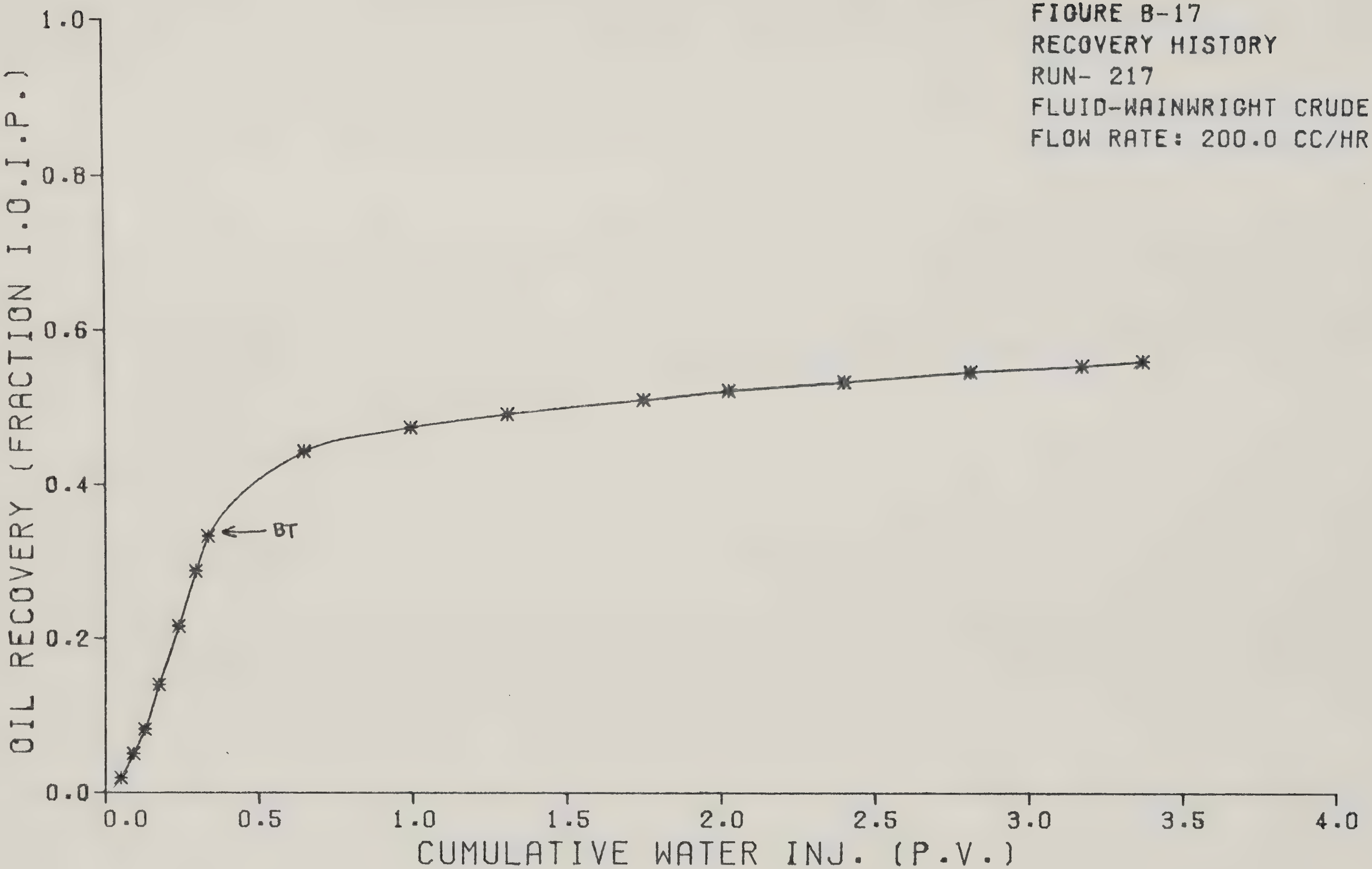


FIGURE B-17
RECOVERY HISTORY
RUN- 217
FLUID-WAINWRIGHT CRUDE
FLOW RATE: 200.0 CC/HR

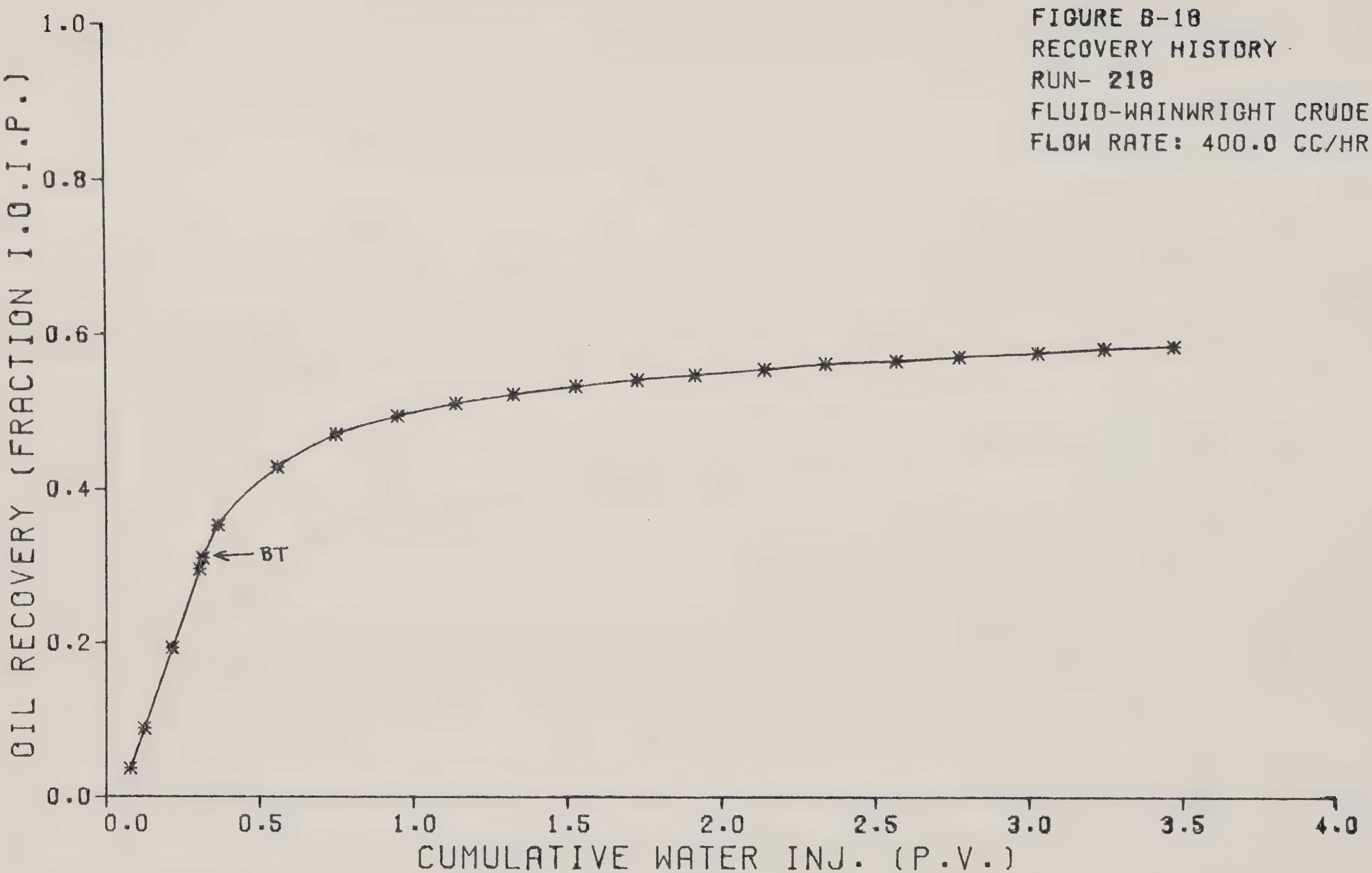


FIGURE B-18
RECOVERY HISTORY
RUN- 218
FLUID-WAINWRIGHT CRUDE
FLOW RATE: 400.0 CC/HR
BT
OIL RECOVERY (FRACTION I.O.I.P.)
CUMULATIVE WATER INJ. (P.V.)
0.0
0.2
0.4
0.6
0.8
1.0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0

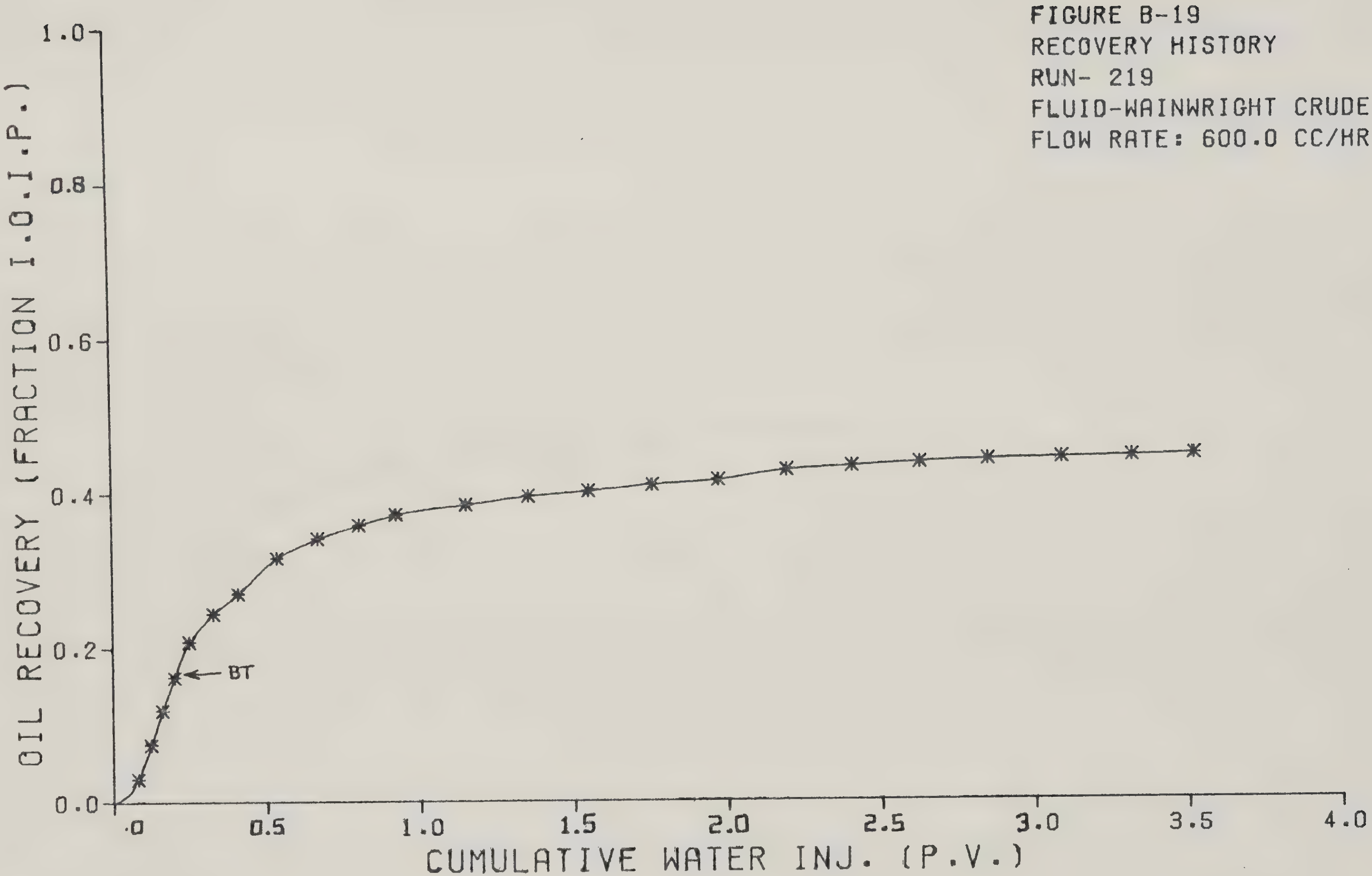


FIGURE B-19
RECOVERY HISTORY
RUN- 219
FLUID-WAINWRIGHT CRUDE
FLOW RATE: 600.0 CC/HR
OIL RECOVERY (FRACTION I.O.I.P.)
CUMULATIVE WATER INJ. (P.V.)
BT
0.0
0.2
0.4
0.6
0.8
1.0
.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0

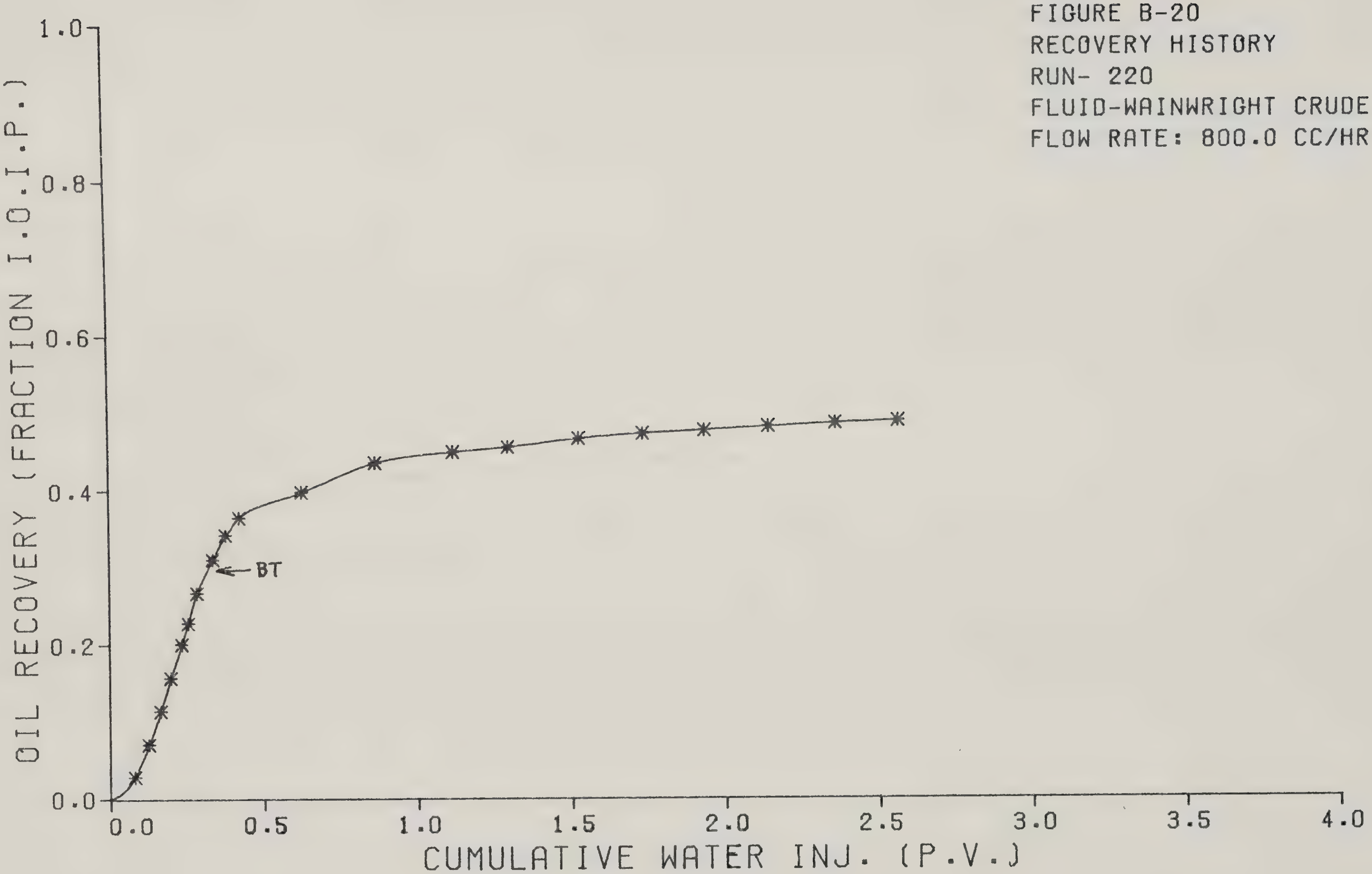
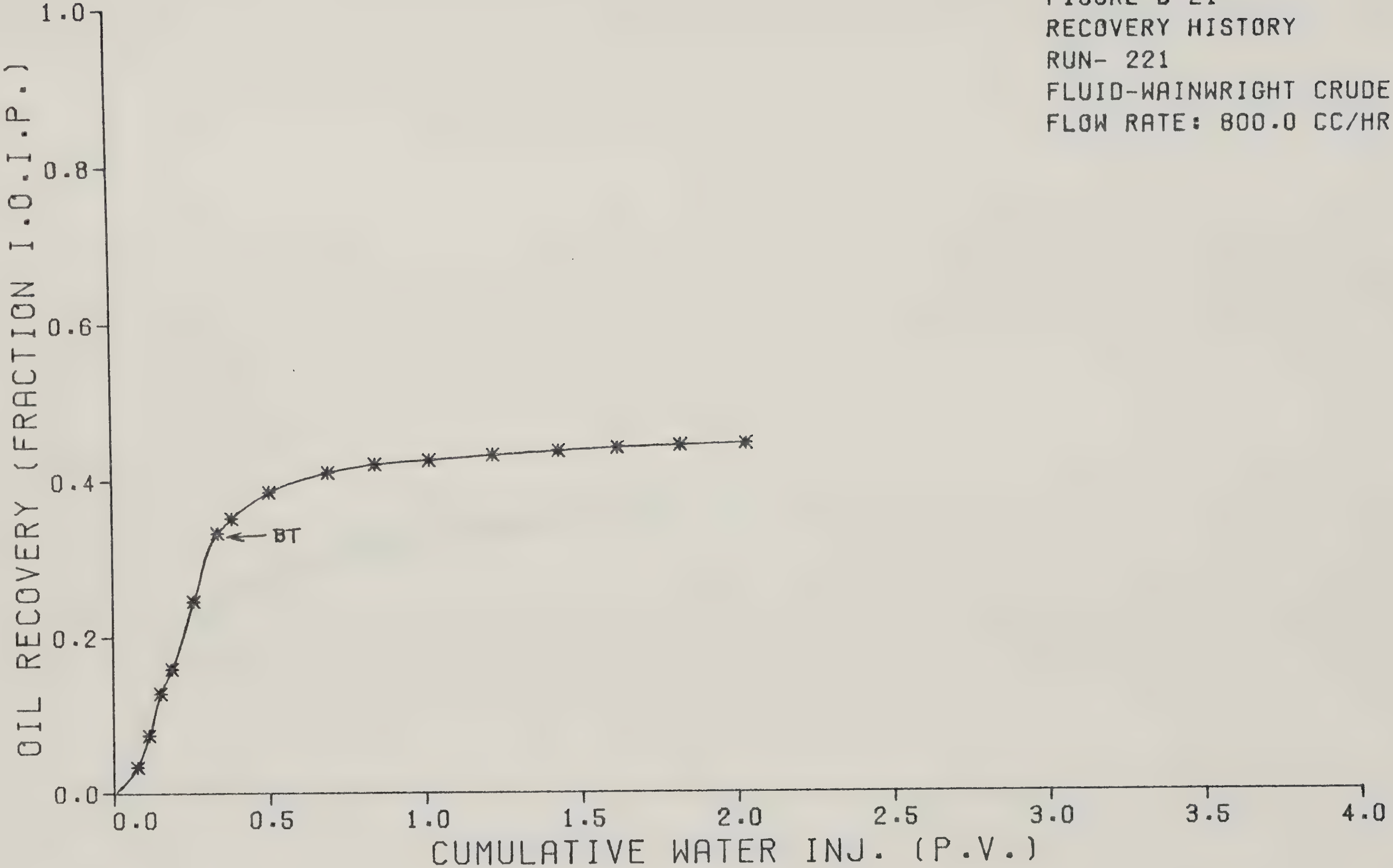


FIGURE B-20
RECOVERY HISTORY
RUN- 220
FLUID-WAINWRIGHT CRUDE
FLOW RATE: 800.0 CC/HR

FIGURE B-21
RECOVERY HISTORY
RUN- 221
FLUID-WAINWRIGHT CRUDE
FLOW RATE: 800.0 CC/HR



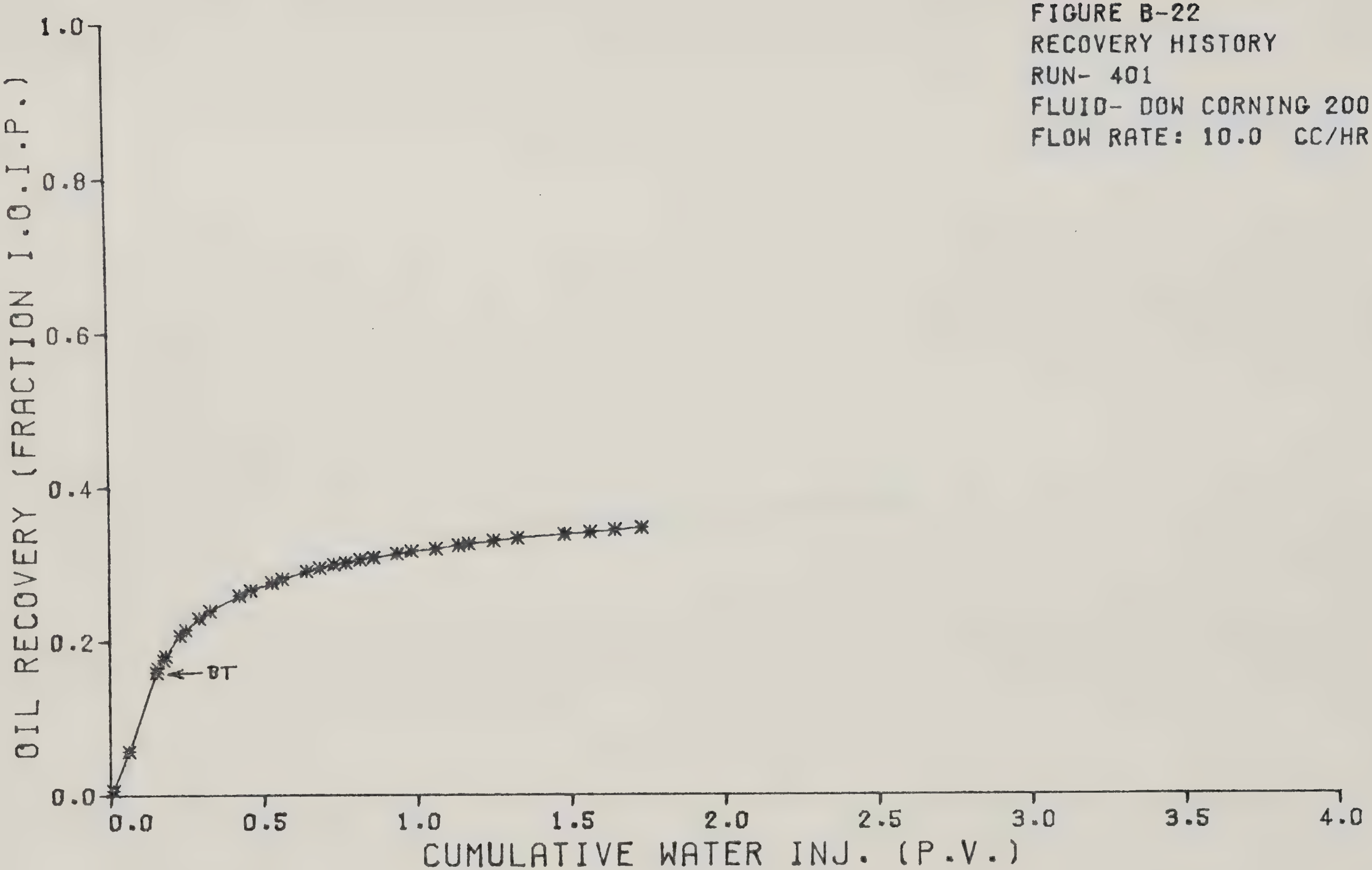


FIGURE B-22
RECOVERY HISTORY
RUN- 401
FLUID- DOW CORNING 200
FLOW RATE: 10.0 CC/HR

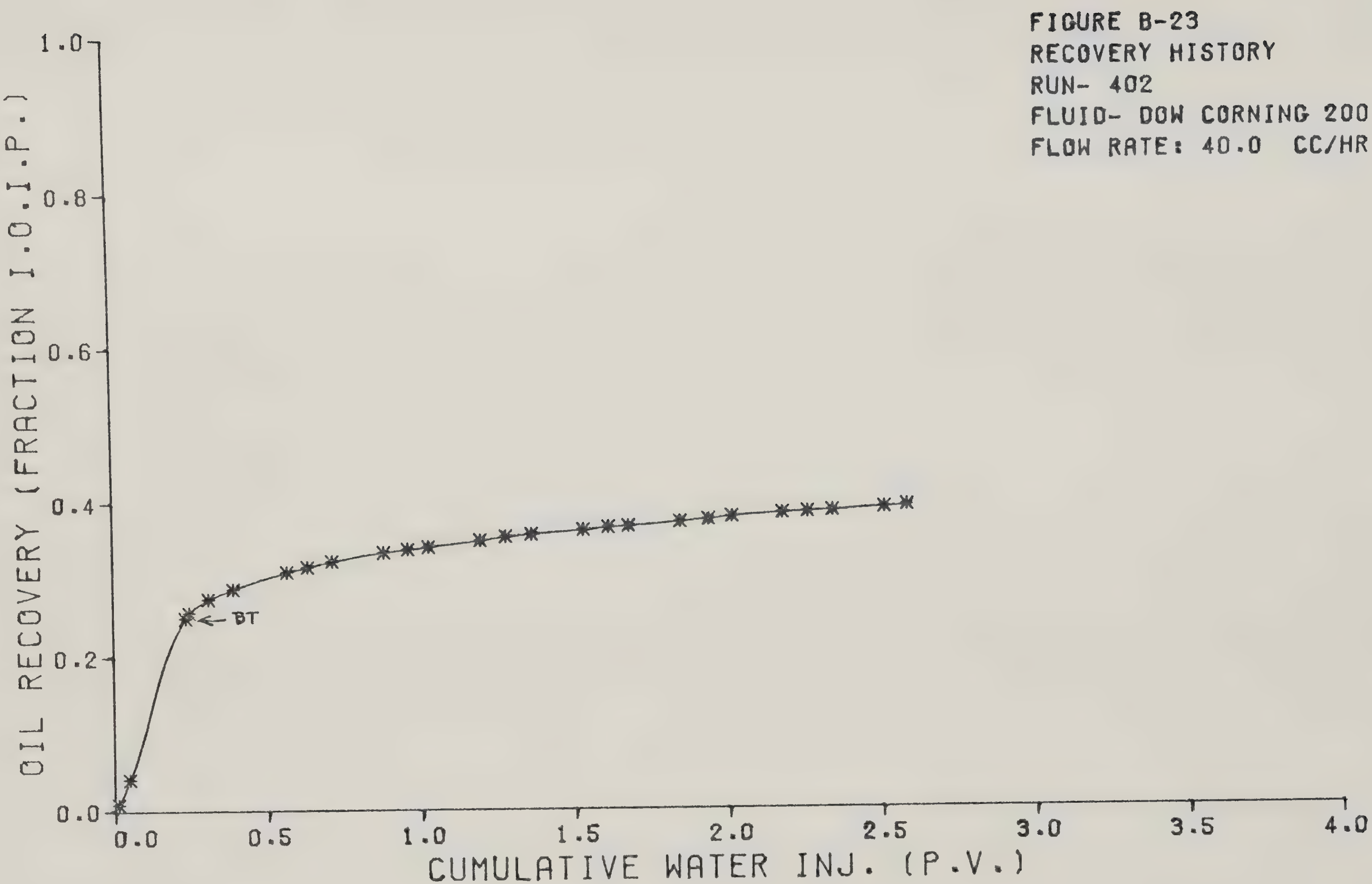


FIGURE B-23
RECOVERY HISTORY
RUN- 402
FLUID- DOW CORNING 200
FLOW RATE: 40.0 CC/HR
OIL RECOVERY (FRACTION I.O.I.P.)
1.0
0.8
0.6
0.4
0.2
0.0
BT
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
CUMULATIVE WATER INJ. (P.V.)

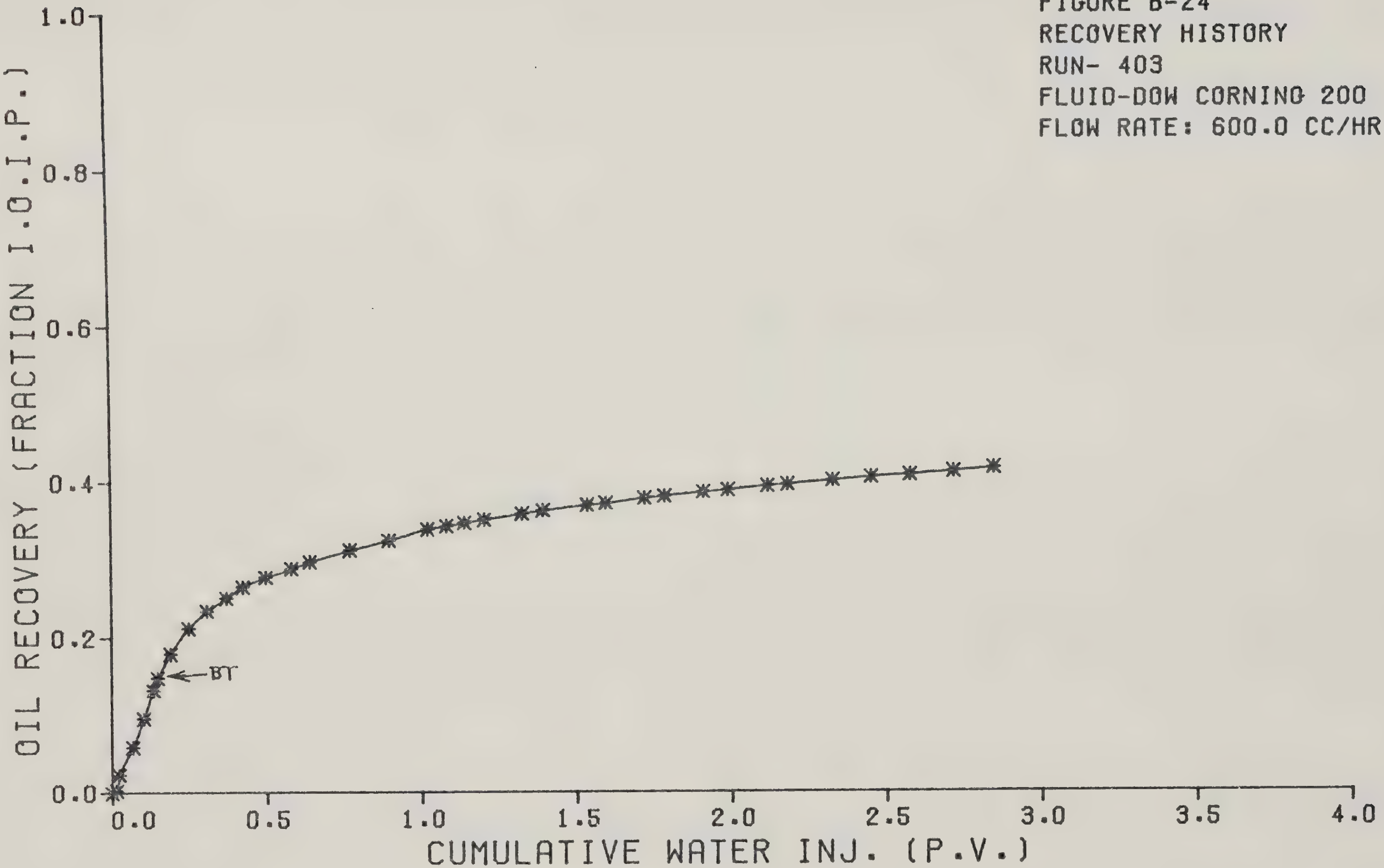


FIGURE B-24
RECOVERY HISTORY
RUN- 403
FLUID-DOW CORNING 200
FLOW RATE: 600.0 CC/HR

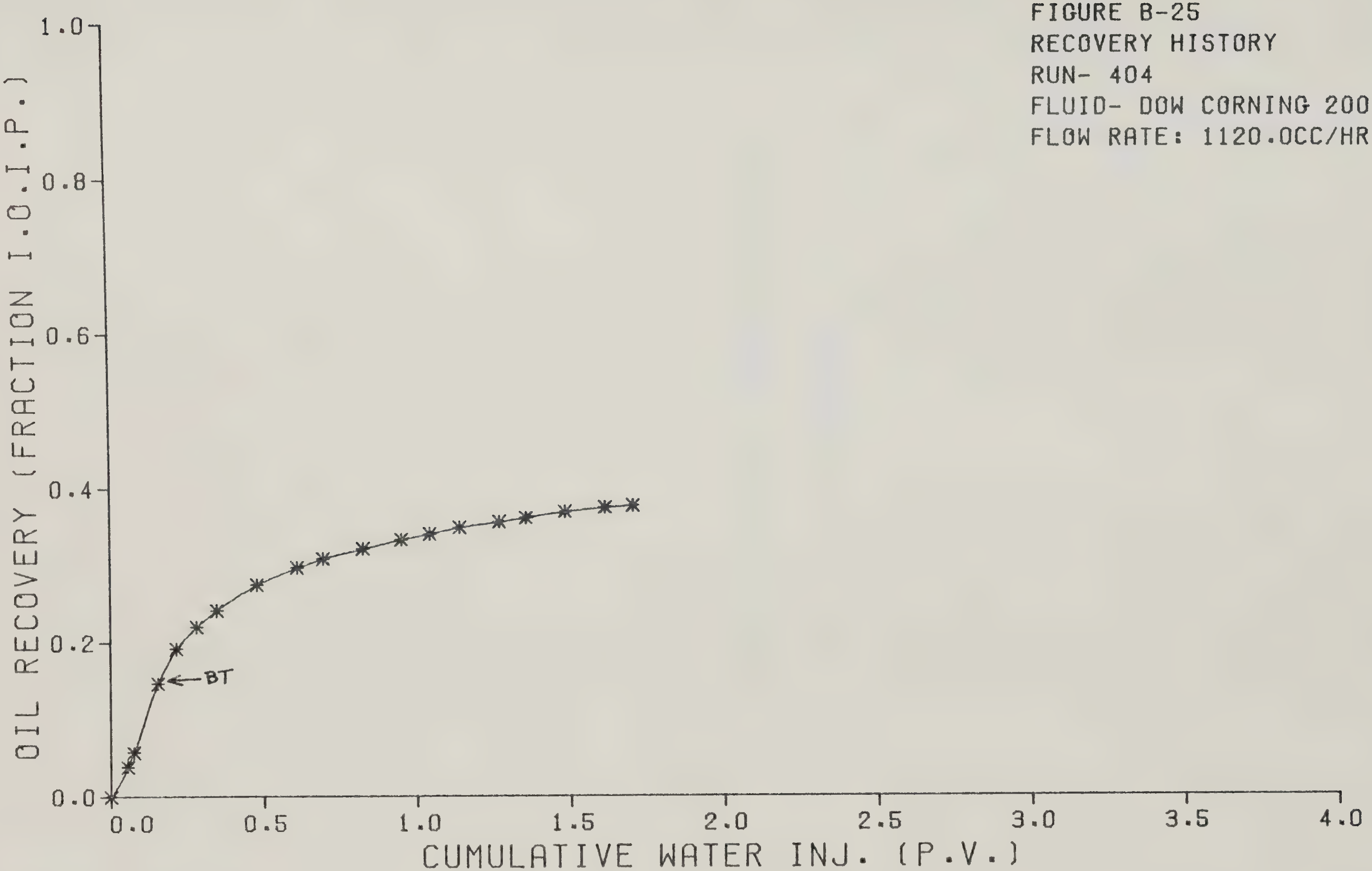


FIGURE B-25
RECOVERY HISTORY
RUN- 404
FLUID- DOW CORNING 200
FLOW RATE: 1120.0CC/HR

APPENDIX C

RELATIVE PERMEABILITY CALCULATIONS

RELATIVE PERMEABILITY CALCULATIONS

The method employed is an extension of the Welge[22] method for finding the relative permeability ratios. It was presented by Johnson et al.[11]

Two conditions must be met before the method is applicable:

(i) stabilized displacement

(ii) flow velocity is constant at all cross-sections.

The first condition implies that the pressure drop across the core be large enough to negate any capillary end effects or ensure that the zone where capillary effects dominate is compressed to a small fraction of the pore space. Implicit in the second condition is immiscible and incompressible fluids and a homogeneous and linear system.

Following the procedure of Leverett*

for the oil phase

$$q_o = -\frac{K_o}{\mu_o}\left[\frac{\partial P_o}{\partial X} - g\rho_o \sin\alpha\right] \qquad (1)$$

and for the water phase

$$q_w = -\frac{K_w}{\mu_w}\left[\frac{\partial P_w}{\partial X} - g\rho_w \sin\alpha\right] \qquad (2)$$

at any point in the core

$$q_t = q_o + q_w$$

---

* Leverett, M.C., Trans. AIME (1939), 132, 149.

and Equations (1), (2) and (3) can be combined to obtain

$$f_w = \frac{q_w}{q_t} = \frac{1 + \frac{K_o}{q_t\ \mu_o}\left\{\frac{\partial P_c}{\partial X} - g\Delta\rho\ sin\ \alpha\right\}}{1 + \frac{K_o\ \mu_w}{K_w\ \mu_o}} \qquad (3)$$

where $$\frac{\partial P_c}{\partial X} = \frac{\partial P_o}{\partial X} - \frac{\partial P_w}{\partial X} \qquad (4)$$

and $$\Delta\rho = \rho_w - \rho_o$$

for a horizontal system; $sin\ \alpha = sin\ 0 = 0$

and using the assumption that the pressure drop across the system is large enough to negate the capillary pressure gradient, the shortened form of the fractional flow equation is obtained:

as $$\frac{\partial P_c}{\partial X} \rightarrow 0$$

$$f_w = \left[1 + \frac{K_o\ \mu_w}{K_w\ \mu_o}\right]^{-1} \qquad (5)$$

or $$f_o = 1 - f_w = \left[1 + \frac{K_w\ \mu_o}{K_o\ \mu_w}\right]^{-1} \qquad (6)$$

from Buckley and Leverett*; the material balance on a thin slice of the reservoir is

$$v\frac{\partial f_w}{\partial X} = \frac{\partial S}{\partial t} = 0 \qquad (7)$$

and since f_w is a function of S only we may write

$$\frac{\partial f_w}{\partial X} = \frac{df_w}{dS}\frac{\partial S}{\partial X} \qquad (8)$$

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* Buckley, S.E. and Leverett, M.C., Pet. Tech., May, 1941.

now by substituting Equation (8) into (7)

$$v \frac{df_w}{dS} = \frac{-\frac{\partial S}{\partial t}}{\frac{\partial S}{\partial X}} = \left(\frac{\partial X}{\partial t}\right)_s = \left(\frac{\Delta X}{\Delta t}\right)_s = v\, f_w' \qquad (9)$$

where $f_w' = \frac{df_w}{dS}$

by evaluating Equation (9) at the outflow face

$$\frac{L}{\Delta t} = v\, f_w' \quad \text{or} \quad \frac{1}{f_w'} = \frac{\Delta t\ v}{L} = \frac{\Delta t\ q}{\phi\ AL} = W_i \qquad (10)$$

the average water saturation in the core could be taken as

$$S_{av} = \frac{\int_1^2 S dx}{L} \qquad (11)$$

and from Equation (10) it is apparent that the distance a fixed saturation moves in the core is proportional to f_w' and then L could be represented by f_{w2}'

therefore $$S_{av} = \frac{\int_1^2 S df_w}{f_{w2}'} \qquad (12)$$

This equation can be integrated by parts to yield

$$S_{av} = \frac{f_w' S \Big|_1^2 - \int_1^2 f_w' dS}{f_{w2}'} = \frac{f_{w2}' S_2 - f_{w1}' S_1 - \int_1^2 f_w' dS}{f_{w2}'} \qquad (13)$$

but $S_1 \simeq 1$, therefore $f_{w1}' = 0$.

then $$S_{av} = S_2 - \frac{\int_1^2 df_w}{f'_{w2}} = S_2 - \frac{f_{w2} - 1}{f'_{w2}} \qquad (14)$$

or $$S_{av} = S_2 + f_{o2} W_i \qquad (15)$$

at any particular instant the pressure drop across the core could be given as

$$\Delta P = -\int_1^2 \frac{\delta P}{\delta X} dx \qquad (16)$$

also from Darcy

$$q = \frac{-KA}{\mu} \frac{\delta P}{\delta X} \quad \text{or} \quad f_o u = \frac{-KK_{ro}}{\mu_o} \frac{\delta P}{\delta X} \qquad (17)$$

substitution of Equation (17) into (16) yields

$$\Delta P = \int_1^2 \frac{f_o u \mu_o}{K K_{ro}} dx = \frac{u \mu_o}{K} \int_1^2 \frac{f_o}{K_{ro}} dx \qquad (18)$$

again by making use of the fact that the distance travelled in the core by a particular displacing saturation is proportional to f_w , Equation (18) may be written as

$$\int_1^2 \frac{f_o}{K_{ro}} dx = \int_0^{f'_{w2}} \frac{f_o}{K_{ro}} df'_w = \frac{\Delta P K f'_{w2}}{u \mu_o L} = f'_{w2} \frac{u_s/\Delta P_s}{u/\Delta P} = \frac{f'_{w2}}{I_r} . \qquad (19)$$

An expanded explanation of Equation (18) is essential since the steps involved may not be evident.

The group $\frac{\Delta P \ K}{u \ \mu_o \ L}$ is known as the reciprocal of the

relative injectivity (I_R). The relative injectivity is dimensionless and describes how the intake capacity ($u/\Delta P$) changes with cumulative injection. I_R is simply a comparison of the intake capacity at any time to the intake capacity at the start of the flood. It can be developed as follows:

$$q_o = \frac{K_o A \ \Delta P}{\mu_o \ L} \quad \text{or} \quad u = \frac{K_o \ \Delta P}{\mu_o \ L}$$

at the start of a flood

$$\frac{u_s}{\Delta P_s} = \frac{K_o}{\mu_o L} \tag{20}$$

Also at the very start of a flood, for all practical purposes, only oil is flowing ($K_o = K$).

therefore, $\dfrac{u_s}{\Delta P_s} = \dfrac{K}{\mu_o \ L}$

At any point in the flood the intake capacity is equal to the velocity (u) at that time over the pressure drop (ΔP) at that time.

$$\left(\frac{u}{\Delta P}\right)_t = \frac{u}{\Delta P} \tag{21}$$

now

$$I_R = \frac{u/\Delta P}{u_s/\Delta P_s} = \frac{u/\Delta P}{K/\mu_o L} = \frac{u \ \mu_o \ L}{K \ \Delta P} \tag{22}$$

the reciprocal of this group is present in Equation (19). So from Equation (19),

$$\frac{f_{w2}'}{I_R} = \int_o^{f_{w2}'} \frac{f_o}{K_{ro}} \, df_w'$$

If we differentiate with respect to f'_{w2} Equation (19) becomes.

$$\frac{d(f'_{w2}/I_R)}{d(f'_{w2})} = \frac{f_o}{K_{ro}} \tag{23}$$

From Equation (10) $W_i = 1/f'_{w2}$, therefore Equation (23) becomes

$$\frac{d(1/W_i I_R)}{d(1/W_i)} = \frac{f_o}{K_{ro}} \tag{24}$$

if f_o is known Equation (24) could be solved for K_{ro}. The fraction of oil flowing out of the system could be calculated by noting that the oil flowing out of the system must equal the change in the average saturation in the core over the change in the cumulative amount of water injected, so the fraction of oil in the producing stream at any time may be calculated from

$$f_{o2} = \frac{dS}{d\ W_i} \tag{25}$$

and the K_{ro} can be found from Equation (24). Also by combining Equations (5) and (6)

$$\frac{f_w}{f_o} = \frac{K_w\ \mu_o}{K_o\ \mu_w} = \frac{K_{rw}\ \mu_o}{K_{ro}\ \mu_w} \tag{26}$$

which can be rearranged to yield K_{rw}.

$$K_{rw} = \frac{(1 - f_o)}{f_o} \frac{\mu_w}{\mu_o} K_{ro}$$

The procedure is to fit a curve to a S vs. W_i plot and

evaluate $\frac{dS}{dW_i}$ and also fit a curve to $\frac{1}{W_i I_R}$ vs. $\frac{1}{W_i}$ plot to evaluate $\frac{d\left(\frac{1}{W_i I_R}\right)}{d\left(\frac{1}{W_i}\right)}$ so that the calculation of K_{ro} and K_{rw} is possible.

FIGURE C- 1

CALCULATED RELATIVE PERMEABILITY CURVES
RUN-202
FLUID- DOW CORNING 200
RATE-10 CC/HR

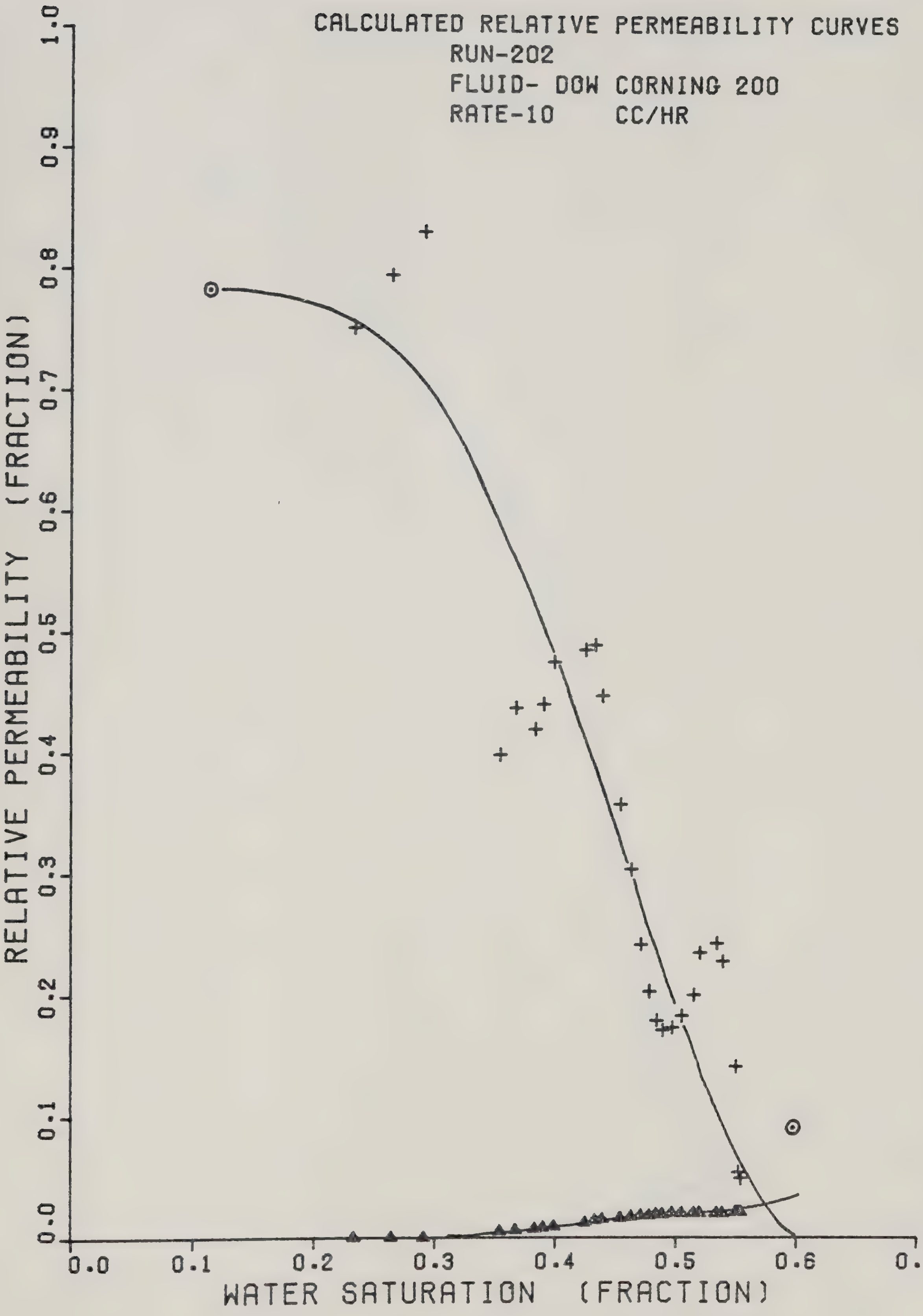


FIGURE C- 2

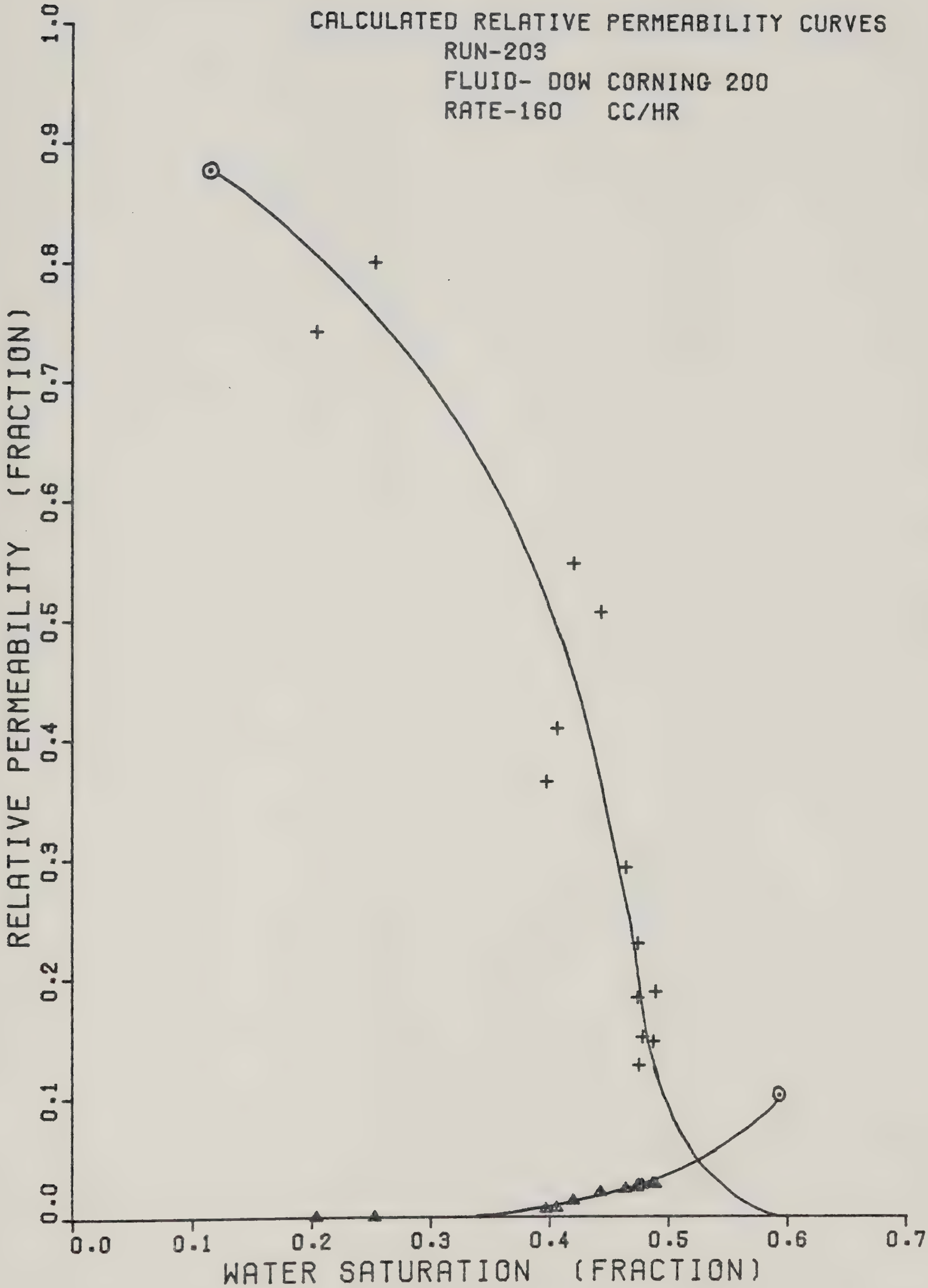

CALCULATED RELATIVE PERMEABILITY CURVES
RUN-203
FLUID- DOW CORNING 200
RATE-160 CC/HR
RELATIVE PERMEABILITY (FRACTION)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
WATER SATURATION (FRACTION)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7

FIGURE C- 3

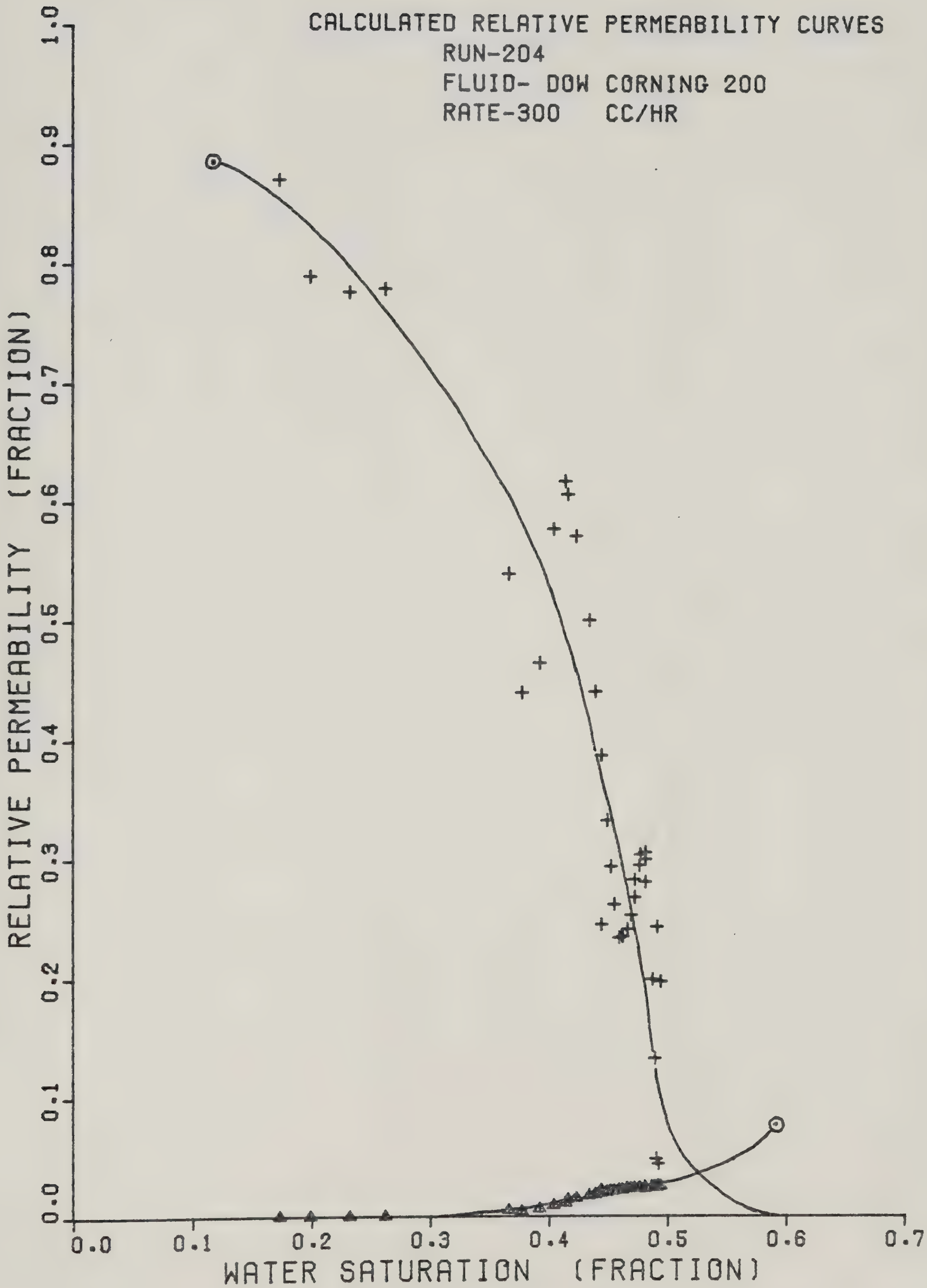

CALCULATED RELATIVE PERMEABILITY CURVES
RUN-204
FLUID- DOW CORNING 200
RATE-300 CC/HR
RELATIVE PERMEABILITY (FRACTION)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
WATER SATURATION (FRACTION)

FIGURE C- 4

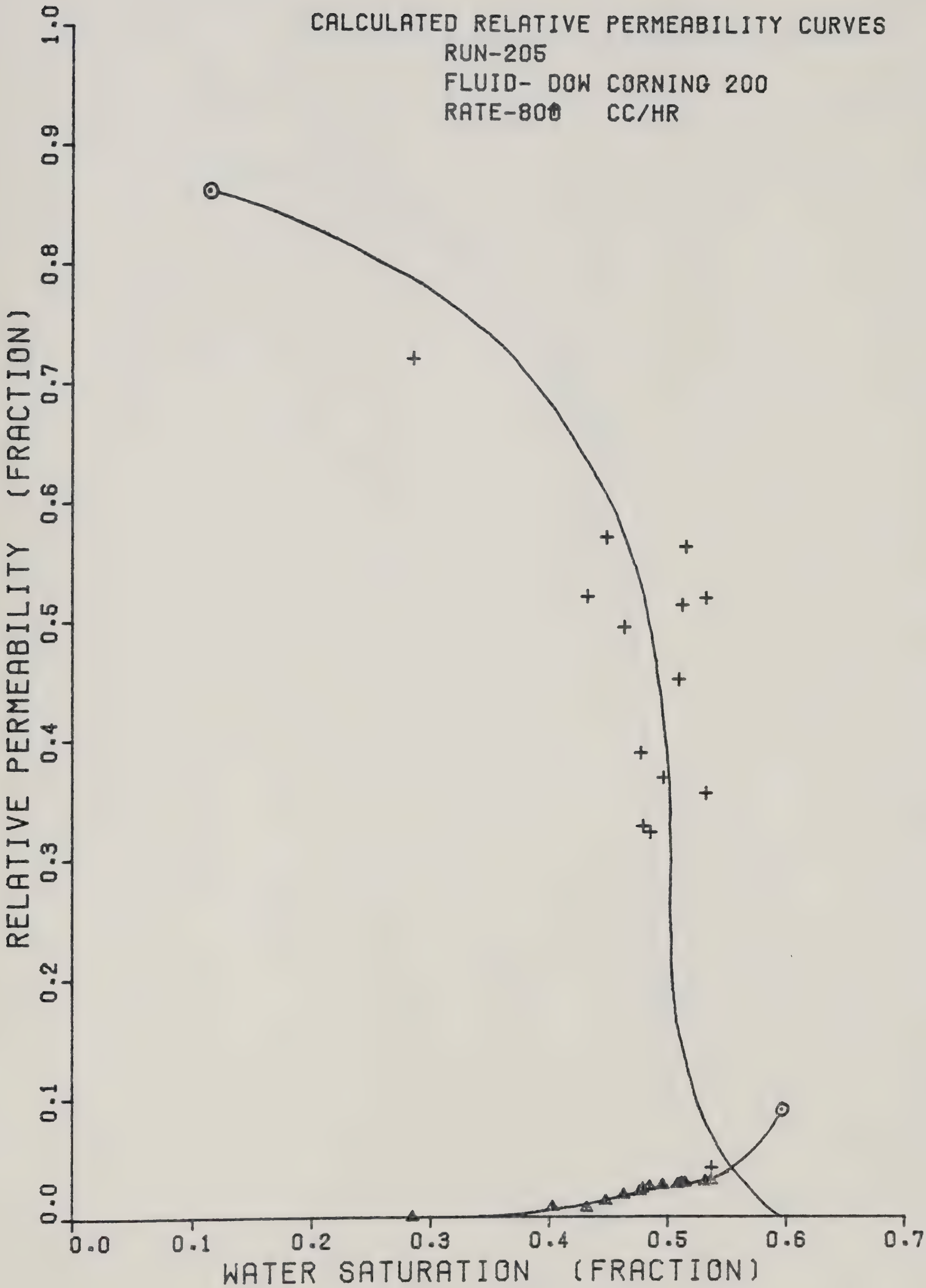

CALCULATED RELATIVE PERMEABILITY CURVES
RUN-205
FLUID- DOW CORNING 200
RATE-800 CC/HR
RELATIVE PERMEABILITY (FRACTION)
WATER SATURATION (FRACTION)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

FIGURE C- 5

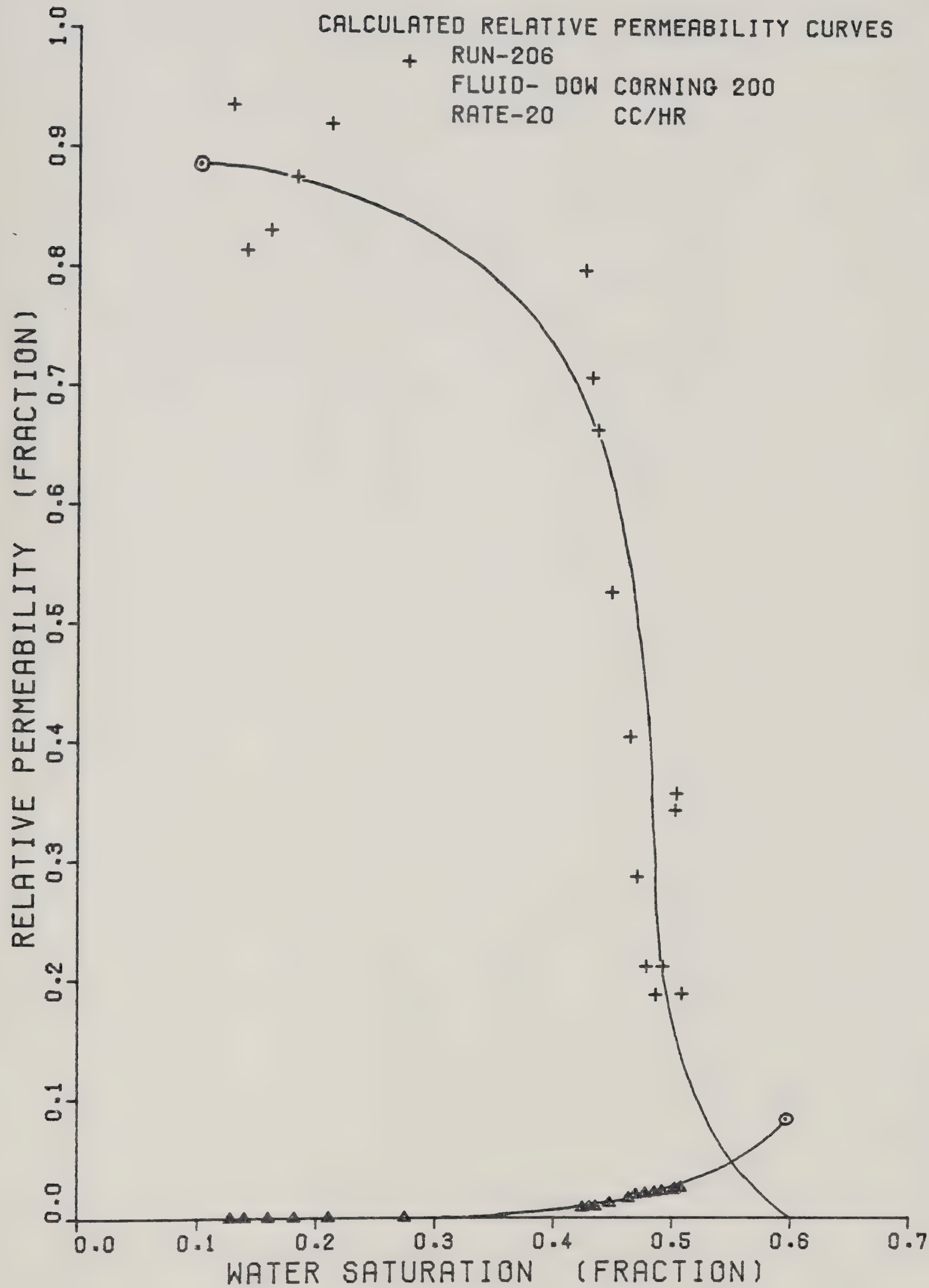

CALCULATED RELATIVE PERMEABILITY CURVES
+ RUN-206
FLUID- DOW CORNING 200
RATE-20 CC/HR
RELATIVE PERMEABILITY (FRACTION)
WATER SATURATION (FRACTION)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

FIGURE C- 6

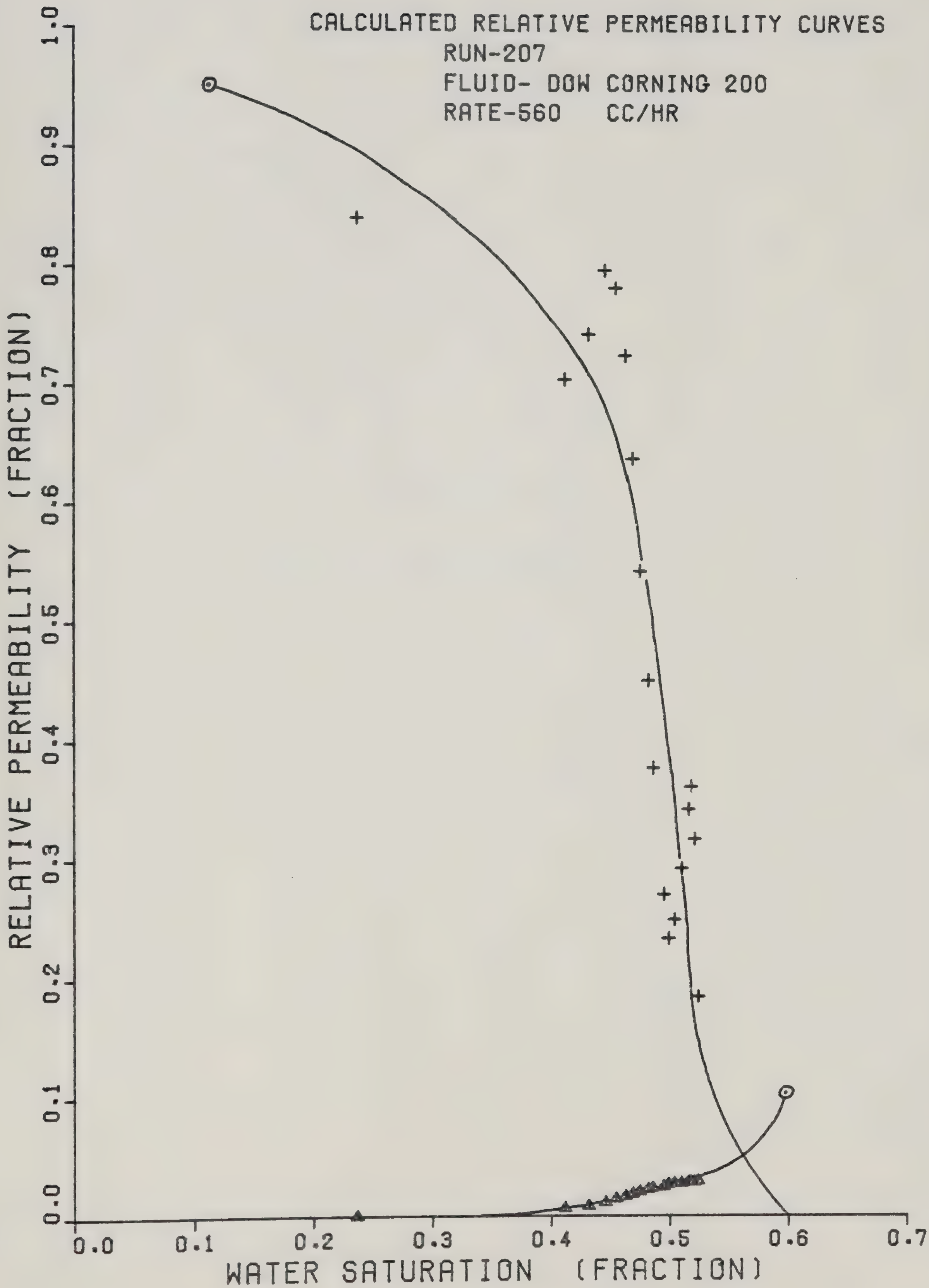
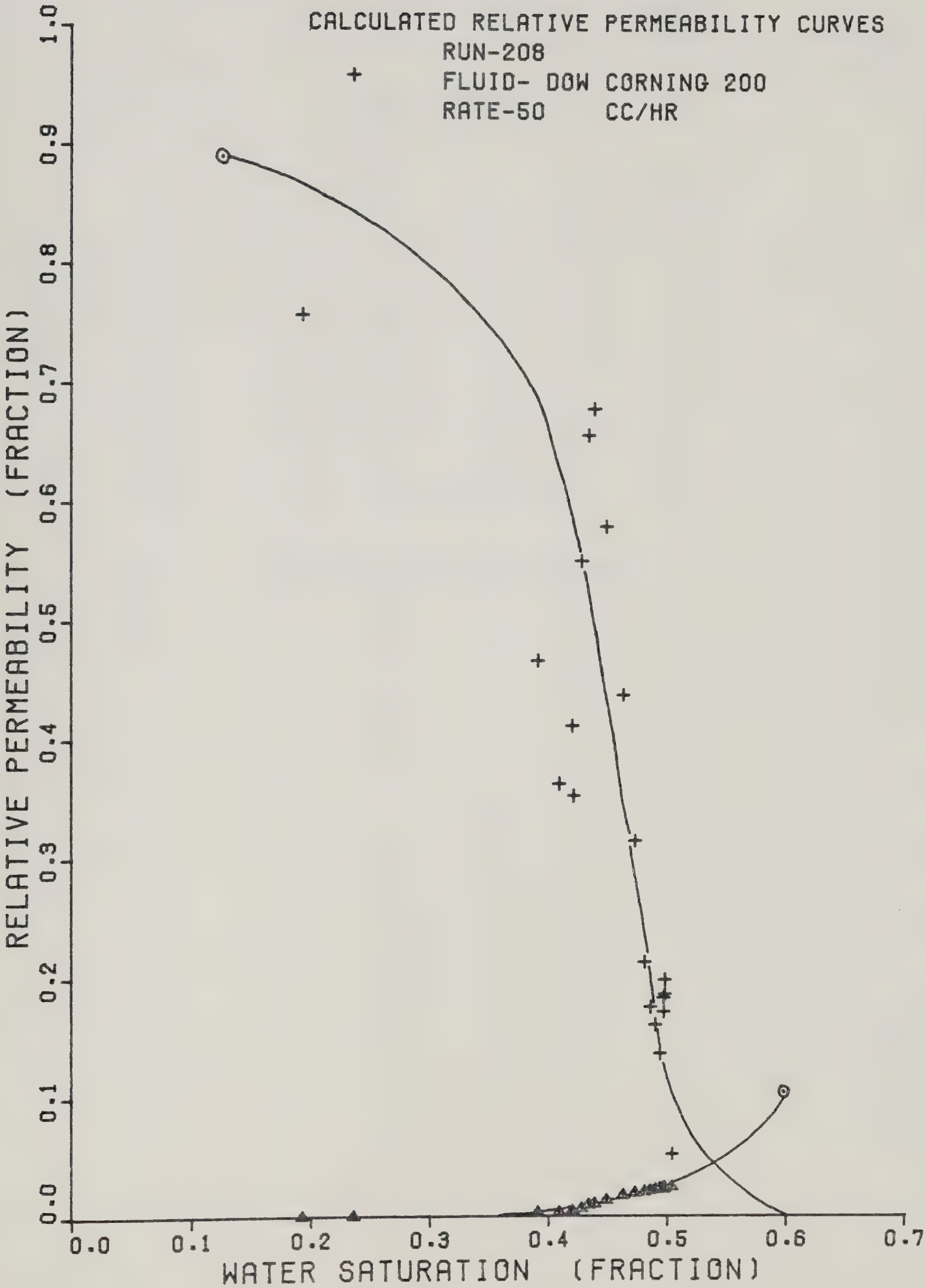

CALCULATED RELATIVE PERMEABILITY CURVES
RUN-207
FLUID- DOW CORNING 200
RATE-560 CC/HR
RELATIVE PERMEABILITY (FRACTION)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
WATER SATURATION (FRACTION)

FIGURE C- 7


CALCULATED RELATIVE PERMEABILITY CURVES
RUN-208
FLUID- DOW CORNING 200
RATE-50 CC/HR
RELATIVE PERMEABILITY (FRACTION)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
WATER SATURATION (FRACTION)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7

APPENDIX D

TABULATED EXPERIMENTAL DATA

TABLE D- 1 (DISPLACEMENT DATA)

RUN-201
DC200(500)CS

Q= 2.5 CC/HR SWI= 9.80 PER CENT K= 15.40 DARCY
TEMP= 22.0 C KOI= 13.35 DARCY
IOIP= 675.6 CC PORE VOL.= 749.0 CC

DATE	TIME (HRS)	PRESS DROP (PSI)	TOTAL INJ (PV)	OIL PROD (CC)	WATER PROD (CC)	TOTAL OIL (% IOIP)	WOR	AVE. SAT.
3101	16.30	0.00	0.000	0.0	0.0	0.00	0.00	0.098
102	23.00	1.64	0.022	17.1	0.0	1.01	0.00	0.120
202	8.45	1.81	0.055	20.9	0.0	4.10	0.00	0.153
202	22.30	1.39	0.101	37.5	0.0	9.65	0.00	0.199
302	23.00	0.79	0.182	60.0	0.0	18.53	0.00	0.280
402	8.50	0.59	0.262	58.7	0.0	27.22	0.00	0.360
502	10.00	0.25	0.300	20.3	8.2	30.22	0.40	0.387
602	14.00	0.19	0.392	17.3	53.2	32.78	3.07	0.408
702	8.45	0.16	0.455	7.1	39.9	33.83	5.61	0.417
702	23.15	0.08	0.503	4.6	32.6	34.51	7.08	0.422
802	17.00	0.06	0.575	5.5	40.5	35.33	7.36	0.440
902	12.00	0.06	0.638	5.2	41.0	36.10	7.88	0.448
902	20.30	0.04	0.666	1.9	19.1	36.38	10.05	0.451
1002	13.30	0.02	0.723	2.9	39.9	36.81	13.75	0.454
1102	8.40	0.02	0.787	4.0	43.0	37.40	10.75	0.461
1102	23.00	0.02	0.834	2.5	36.8	37.77	14.72	0.459
1202	18.45	0.02	0.895	2.8	39.0	38.18	13.92	0.468
1302	13.10	0.02	0.957	3.0	42.5	38.63	14.16	0.473
1402	22.00	0.02	1.066	4.5	78.5	39.29	17.44	0.478
1502	15.50	0.02	1.126	2.5	44.5	39.66	17.80	0.478
1602	10.30	0.02	1.189	2.4	42.6	40.02	17.75	0.484
1702	13.45	0.02	1.250	1.9	42.1	40.30	22.15	0.489
1802	23.00	0.02	1.361	3.7	78.1	40.85	21.10	0.496
1902	11.30	0.02	1.403	1.5	28.5	41.07	19.00	0.499
2002	13.15	0.02	1.489	2.7	62.3	41.47	23.07	0.503
2102	12.30	0.02	1.567	1.8	57.9	41.74	32.16	0.503
2202	13.30	0.02	1.650	2.5	58.3	42.11	23.32	0.508
2302	8.45	0.01	1.714	1.0	43.0	42.25	43.00	0.515
2402	8.40	0.01	1.794	1.6	58.4	42.49	36.50	0.517
2402	22.00	0.01	1.839	2.1	33.2	42.80	15.80	0.518
2602	18.15	0.01	1.986	3.1	105.0	43.26	33.87	0.525
2702	14.00	0.01	2.053	1.6	47.1	43.50	29.43	0.528
203	13.30	0.01	2.290	4.5	174.2	44.16	38.71	0.534
303	8.20	0.01	2.393	1.7	75.5	44.41	44.41	0.536
403	14.45	0.01	2.455	1.4	45.1	44.62	32.21	0.537

TABLE D- 2 (DISPLACEMENT DATA)

RUN-202
DC200(500)CS

Q= 10.0 CC/HR
TEMP= 21.0 C
IOIP= 677.0 CC

SWI=11.26 PER CENT
KOI= 13.55 DARCY
PORE VOL.= 770.4 CC

K= 17.34 DARCY

DATE	TIME (HRS)	PRESS DROP (PSI)	TOTAL INJ (PV)	OIL PROD (CC)	WATER PROD (CC)	TOTAL OIL (% IOIP)	WOR	AVE. SAT.
1004	21.00	0.00	0.000	0.0	0.0	0.00	0.00	0.112
1004	23.30	6.80	0.020	16.0	0.0	0.84	0.00	0.133
1104	7.00	5.10	0.121	77.5	0.0	12.29	0.00	0.233
1104	9.10	4.20	0.151	23.6	0.0	15.77	0.00	0.264
1104	11.10	3.20	0.179	20.9	0.0	18.86	0.00	0.291
1104	13.30	2.00	0.227	37.6	0.0	24.41	0.00	0.340
1104	19.05	1.30	0.282	12.5	31.5	26.26	2.52	0.354
1104	23.00	1.20	0.336	9.5	31.0	27.66	3.26	0.367
1204	9.10	1.00	0.471	12.3	92.0	29.48	7.47	0.383
1204	16.30	0.90	0.567	9.1	68.8	30.82	7.56	0.390
1204	23.25	0.80	0.660	6.2	64.5	31.74	10.40	0.399
1304	23.00	0.70	0.976	15.9	223.0	34.09	14.02	0.425
1404	8.30	0.60	1.099	5.0	89.0	34.83	17.80	0.433
1404	20.40	0.60	1.262	6.0	121.0	35.71	20.16	0.439
1504	23.00	0.60	1.615	9.6	260.5	37.13	27.13	0.454
1604	20.50	0.50	1.902	6.0	214.0	38.02	35.66	0.463
1704	21.10	0.50	2.227	3.8	244.5	38.58	64.34	0.471
1804	19.45	0.50	2.527	6.0	225.0	39.46	37.50	0.478
1904	17.00	0.50	2.811	3.2	215.0	39.94	67.18	0.484
2004	18.15	0.40	3.146	4.2	253.5	40.56	60.35	0.489
2104	22.10	0.40	3.516	5.5	279.5	41.37	50.81	0.497
2204	21.00	0.40	3.822	4.5	229.5	42.03	51.00	0.505
2304	22.30	0.40	4.157	2.5	250.5	42.40	100.20	0.515
2504	20.45	0.30	4.747	6.0	451.0	43.29	75.16	0.520
2604	21.00	0.30	5.074	4.0	248.0	43.88	62.00	0.525
2704	22.45	0.30	5.407	4.0	249.0	44.47	62.25	0.534
2804	22.15	0.30	5.719	2.5	237.0	44.84	94.80	0.539
3004	21.10	0.30	6.344	5.0	473.0	45.58	94.60	0.550
105	22.40	0.30	6.683	2.0	259.0	45.87	129.50	0.552
205	21.00	0.30	6.978	1.0	227.0	46.02	227.00	0.554
305	14.00	0.30	7.206	0.5	174.5	46.10	349.00	0.554

TABLE D- 3 (DISPLACEMENT DATA)

RUN-203
DC200(500)CS

Q= 160.0 CC/HR SWI=11.45 PER CENT K= 16.39 DARCY
TEMP= 21.0 C KOI= 14.31 DARCY
IOIP= 666.2 CC PORE VOL.= 752.4 CC

DATE	TIME (HRS)	PRESS DROP (PSI)	TOTAL INJ (PV)	OIL PROD (CC)	WATER PROD (CC)	TOTAL OIL (% IOIP)	WOR	AVE. SAT.
2405	22.00	0.00	0.000	0.0	0.0	0.00	0.00	0.114
2405	22.10	125.00	0.070	48.0	0.0	5.66	0.00	0.149
2405	22.25	107.20	0.134	40.0	0.0	11.66	0.00	0.204
2405	22.37	79.60	0.199	46.5	0.0	18.64	0.00	0.253
2405	22.56	47.60	0.208	7.3	0.0	19.74	0.00	0.323
2405	23.30	21.50	0.331	45.5	52.4	26.57	1.15	0.376
2505	0.01	15.20	0.448	15.1	72.0	28.83	4.76	0.397
2505	0.33	12.60	0.559	9.4	76.5	30.24	8.13	0.406
2505	1.39	9.20	0.793	12.5	165.3	32.12	13.22	0.420
2505	3.48	6.10	1.251	21.8	327.8	35.39	15.03	0.443
2505	6.23	5.40	1.819	19.0	412.0	38.24	21.68	0.463
2505	7.30	5.20	2.043	5.3	162.0	39.04	30.56	0.473
2505	8.33	4.60	2.269	6.2	169.7	39.97	27.37	0.473
2505	9.36	4.40	2.497	4.9	168.8	40.70	34.44	0.476
2505	11.25	3.90	2.910	7.7	312.8	41.86	40.62	0.474
2505	13.51	3.50	3.415	8.0	371.0	43.06	46.37	0.486
2505	15.55	3.30	3.869	5.0	339.7	43.81	67.93	0.488

TABLE D- 4 (DISPLACEMENT DATA)

RUN-204
DC200(500)CS

Q= 300.0 CC/HR SWI=12.50 PER CENT K= 13.75 DARCY
TEMP= 21.0 C KOI= 12.12 DARCY
IOIP= 680.9 CC PORE VOL.= 778.0 CC

DATE	TIME (HRS)	PRESS DROP (PSI)	TOTAL INJ (PV)	OIL PROD (CC)	WATER PROD (CC)	TOTAL OIL (% IOIP)	WOR	AVE. SAT.
1506	19.50	0.00	0.000	0.0	0.0	0.00	0.00	0.125
1506	19.57	269.00	0.048	36.0	0.0	3.77	0.00	0.173
1506	20.00	242.00	0.074	16.0	0.1	6.12	0.00	0.199
1506	20.05	200.00	0.107	23.0	0.3	9.50	0.01	0.232
1506	20.10	160.00	0.138	22.0	0.4	12.73	0.01	0.262
1506	20.17	108.00	0.179	28.9	0.5	16.98	0.01	0.303
1506	20.27	70.00	0.246	32.0	21.0	21.68	0.65	0.343
1506	20.38	49.60	0.312	20.5	32.5	24.69	1.58	0.366
1506	20.45	41.50	0.363	9.0	32.0	26.01	3.55	0.377
1506	21.00	32.50	0.472	12.7	72.8	27.87	5.73	0.392
1506	21.20	26.60	0.595	10.6	85.9	29.43	8.10	0.404
1506	21.36	23.20	0.704	8.1	76.4	30.62	9.43	0.416
1506	21.54	20.60	0.817	6.4	81.6	31.56	12.75	0.423
1506	22.10	18.70	0.915	7.0	83.1	32.59	11.87	0.414
1506	22.28	17.20	1.046	6.4	86.5	33.53	13.51	0.434
1506	22.45	15.80	1.159	5.5	84.0	34.33	15.27	0.439
1506	23.20	14.00	1.390	8.0	172.7	35.51	21.58	0.449
1506	23.37	13.10	1.503	3.4	85.7	36.01	25.20	0.452
1606	0.14	11.80	1.736	6.6	186.6	36.98	28.27	0.444
1606	0.33	11.40	1.871	2.5	93.9	37.34	37.56	0.459
1606	1.10	10.30	2.118	4.8	186.2	38.05	38.79	0.466
1606	1.28	10.00	2.233	2.7	88.1	38.44	32.62	0.469
1606	2.06	9.30	2.361	2.3	97.4	38.78	42.34	0.471
1606	2.23	9.00	2.473	2.5	85.6	39.15	34.24	0.473
1606	2.41	8.70	2.588	2.0	89.0	39.44	44.50	0.474
1606	3.00	8.50	2.712	2.0	93.3	39.74	46.65	0.478
1606	3.36	8.00	2.953	3.1	188.1	40.19	60.67	0.477
1606	3.55	7.70	3.089	2.4	97.6	40.54	40.66	0.488
1606	4.12	7.60	3.194	1.8	85.2	40.81	47.33	0.483
1606	4.48	7.20	3.428	2.4	181.0	41.16	75.41	0.485
1606	5.06	7.00	3.530	1.7	90.1	41.41	53.00	0.470
1606	5.24	6.90	3.666	1.5	90.0	41.63	60.00	0.491

TABLE D- 5 (DISPLACEMENT DATA)

RUN-205
DC200(500)CS

Q= 800.0 CC/HR   SWI=11.44 PER CENT   K= 8.43 DARCY
TEMP= 22.0 C   KOI= 7.30 DARCY
IOIP= 665.1 CC   PORE VOL.= 751.0 CC

DATE	TIME (HRS)	PRESS DROP (PSI)	TOTAL INJ (PV)	OIL PROD (CC)	WATER PROD (CC)	TOTAL OIL (% IOIP)	WOR	AVE. SAT.
2806	8.24	0.00	0.000	0.0	0.0	0.00	0.00	0.114
2806	8.29	1065.00	0.089	42.6	0.4	4.86	0.00	0.203
2806	8.34	470.00	0.177	42.2	3.8	11.20	0.09	0.285
2806	8.37	310.00	0.238	23.5	4.8	14.73	0.20	0.340
2806	8.42	225.00	0.320	20.6	45.0	17.83	2.18	0.363
2806	8.49	160.00	0.443	26.0	62.0	21.74	2.38	0.403
2806	9.02	111.20	0.683	29.4	157.7	26.16	5.36	0.432
2806	9.15	84.50	0.928	20.0	172.0	29.17	8.60	0.448
2806	9.29	70.00	1.183	18.3	180.7	31.92	9.87	0.463
2806	9.49	60.40	1.436	10.3	180.1	33.47	17.48	0.477
2806	10.02	54.20	1.679	9.3	180.3	34.87	19.38	0.479
2806	10.16	49.20	1.929	9.9	183.3	36.35	18.51	0.485
2806	10.29	45.10	2.174	8.1	175.9	37.57	21.71	0.496
2806	10.44	41.50	2.445	10.0	194.0	39.08	19.40	0.509
2806	10.59	39.50	2.655	5.1	150.2	39.84	29.45	0.519
2806	11.21	36.80	2.963	8.0	222.0	41.05	27.75	0.531
2806	11.36	34.70	3.226	6.5	177.2	42.02	27.26	0.558
2806	11.50	33.00	3.487	5.2	195.8	42.80	37.65	0.559
2806	12.04	31.40	3.740	4.0	186.0	43.41	46.50	0.564
2806	12.17	30.20	3.984	6.0	182.0	44.31	30.33	0.566

TABLE D- 6 (DISPLACEMENT DATA)

RUN-206
DC200(500)CS

Q= 20.0 CC/HR SWI=10.58 PER CENT K= 7.56 DARCY
TEMP= 22.0 C KOI= 6.66 DARCY
IOIP= 665.5 CC PORE VOL.= 744.3 CC

DATE	TIME (HRS)	PRESS DROP (PSI)	TOTAL INJ (PV)	OIL PROD (CC)	WATER PROD (CC)	TOTAL OIL (% IOIP)	WOR	AVE. SAT.
707	13.00	0.00	0.000	0.0	0.0	0.00	0.00	0.105
707	13.52	35.40	0.022	14.4	0.0	0.62	0.00	0.128
707	14.18	34.00	0.034	7.9	0.0	1.80	0.00	0.140
707	15.00	31.60	0.054	12.1	0.0	3.62	0.00	0.159
707	15.50	28.80	0.076	17.1	0.0	6.19	0.00	0.182
707	16.53	25.20	0.105	23.0	0.0	9.65	0.00	0.211
707	19.11	17.70	0.169	47.2	0.0	16.74	0.00	0.274
707	21.14	10.30	0.225	44.0	0.0	23.35	0.00	0.331
707	22.01	8.20	0.246	16.7	0.2	25.87	0.01	0.352
707	23.02	6.50	0.275	1.4	10.6	26.08	7.57	0.366
807	7.41	3.80	0.512	45.0	133.0	32.84	2.95	0.425
807	10.11	3.40	0.582	5.3	47.7	33.64	9.00	0.431
807	12.25	3.20	0.644	4.7	42.2	34.34	8.97	0.436
807	21.03	2.80	0.878	14.1	165.4	36.46	11.73	0.447
907	5.04	2.30	1.102	11.0	155.0	38.11	14.09	0.464
907	13.10	2.00	1.321	9.4	158.3	39.53	16.84	0.470
907	21.15	1.80	1.540	8.2	157.1	40.76	19.15	0.478
1007	5.23	1.70	1.762	6.3	158.8	41.70	25.20	0.486
1007	13.23	1.60	1.984	5.9	161.0	42.59	27.28	0.491
1107	9.35	1.50	2.540	14.6	406.1	44.78	27.81	0.502
1107	15.30	1.50	2.678	2.4	102.9	45.14	42.87	0.502
1207	10.15	1.20	3.191	11.4	377.6	46.86	33.12	0.508
1207	20.45	1.10	3.484	4.4	210.0	47.52	47.72	0.519

TABLE D- 7 (DISPLACEMENT DATA)

RUN-207
DC200(500)CS

Q= 560.0 CC/HR   SWI=11.86 PER CENT   K= 8.54 DARCY
TEMP= 21.0 C   KOI= 8.18 DARCY
IOIP= 674.6 CC   PORE VOL.= 765.4 CC

DATE	TIME (HRS)	PRESS DROP (PSI)	TOTAL INJ (PV)	OIL PROD (CC)	WATER PROD (CC)	TOTAL OIL (% IOIP)	WOR	AVE. SAT.
1007	12.43	0.00	0.000	0.0	0.0	0.00	0.00	0.118
1007	12.48	660.00	0.052	30.0	0.0	3.21	0.00	0.170
1007	12.49	675.00	0.066	7.0	0.0	4.25	0.00	0.185
1007	12.54	544.00	0.118	35.0	0.0	9.44	0.00	0.237
1007	12.57	424.00	0.150	18.0	0.0	12.11	0.00	0.268
1007	13.00	290.00	0.188	27.4	3.2	16.17	0.11	0.302
1007	13.09	158.00	0.303	42.4	49.6	22.46	1.16	0.352
1007	13.19	110.00	0.423	23.3	69.5	25.91	2.98	0.382
1007	13.30	86.40	0.551	16.2	74.4	28.32	4.59	0.412
1007	13.40	72.20	0.677	11.0	79.7	29.95	7.24	0.434
1007	13.50	62.50	0.794	10.1	81.1	31.44	8.02	0.446
1007	14.00	56.00	0.916	8.3	85.7	32.67	10.32	0.455
1007	14.09	50.60	1.036	7.7	86.3	33.82	11.20	0.463
1007	14.20	46.40	1.158	5.7	88.3	34.66	15.49	0.469
1007	14.30	42.50	1.283	6.6	91.4	35.64	13.84	0.475
1007	14.40	40.00	1.406	4.2	88.8	36.26	21.14	0.482
1007	14.49	38.00	1.520	4.4	83.6	36.91	19.00	0.486
1007	15.10	33.80	1.770	9.2	185.0	38.28	20.10	0.495
1007	15.30	30.40	2.013	6.9	182.8	39.30	26.49	0.499
1007	15.50	28.40	2.252	6.4	179.0	40.25	27.96	0.504
1007	16.09	26.80	2.482	6.5	171.6	41.21	26.40	0.510
1007	16.30	24.60	2.736	4.5	190.6	41.88	42.35	0.516
1007	16.49	23.20	2.974	4.4	180.4	42.53	41.00	0.518
1007	17.09	22.10	3.220	4.6	185.3	43.21	40.28	0.521
1007	17.30	21.00	3.458	4.4	180.4	43.87	41.00	0.524
1007	17.50	20.20	3.699	3.0	181.7	44.31	60.56	0.527
1007	18.09	19.40	3.926	4.2	179.2	44.93	42.66	0.520

TABLE D- 8 (DISPLACEMENT DATA)

RUN-208
DC200(500)CS

Q= 50.0 CC/HR   SWI=12.46 PER CENT   K= 16.72 DARCY
TEMP= 21.0 C   KOI= 14.95 DARCY
IOIP= 688.0 CC   PORE VOL.= 785.9 CC

DATE	TIME (HRS)	PRESS DROP (PSI)	TOTAL INJ (PV)	OIL PROD (CC)	WATER PROD (CC)	TOTAL OIL (%IOIP)	WOR	AVE. SAT.
1307	11.50	0.00	0.000	0.0	0.0	0.00	0.00	0.124
1307	12.20	35.90	0.033	20.0	0.0	1.56	0.00	0.157
1307	12.56	31.10	0.068	21.0	0.0	4.62	0.00	0.193
1307	13.22	27.00	0.111	33.0	0.0	9.41	0.00	0.236
1307	13.41	22.80	0.132	11.1	0.0	11.03	0.00	0.256
1307	14.57	12.00	0.213	67.9	0.1	20.90	0.00	0.338
1307	15.40	10.50	0.251	19.3	9.7	23.70	0.50	0.364
1307	16.20	8.30	0.309	21.2	23.8	26.78	1.12	0.391
1307	17.00	6.80	0.366	14.2	30.5	28.85	2.14	0.409
1307	17.40	5.50	0.422	9.4	34.6	30.21	3.68	0.421
1307	18.30	4.90	0.468	7.0	37.0	31.23	5.28	0.420
1307	19.40	4.00	0.524	6.2	37.8	32.13	6.09	0.428
1307	20.34	3.40	0.580	5.1	39.1	32.87	7.66	0.434
1307	21.27	3.20	0.636	3.8	39.8	33.43	10.47	0.439
1407	0.30	3.00	0.843	13.3	155.0	35.36	11.65	0.449
1407	3.45	2.60	1.066	12.0	164.2	37.10	13.68	0.463
1407	7.20	2.10	1.278	8.6	159.1	38.35	18.50	0.473
1407	10.50	2.00	1.501	7.0	168.8	39.37	24.11	0.481
1407	13.20	1.80	1.665	5.9	125.2	40.23	21.22	0.486
1407	16.45	1.60	1.884	7.4	168.8	41.30	22.81	0.490
1407	20.16	1.60	2.108	5.9	170.1	42.16	28.83	0.497
1407	21.55	1.50	2.222	2.4	90.6	42.51	37.75	0.497
1507	0.31	1.50	2.451	3.8	182.0	43.06	47.89	0.494
1507	3.59	1.40	2.673	3.8	171.0	43.61	45.00	0.498
1507	7.00	1.30	2.864	3.3	152.7	44.09	46.27	0.494
1507	10.21	1.30	3.028	2.6	121.9	44.47	46.88	0.504
1507	15.10	1.20	3.343	3.8	250.2	45.02	65.84	0.500

TABLE D- 9 (DISPLACEMENT DATA)

RUN-209
DC200(500)CS

Q= 15.0 CC/HR SWI= 9.70 PER CENT K= 8.66 DARCY
TEMP= 22.0 C KOI= 8.18 DARCY
IOIP= 648.8 CC PORE VOL.= 718.4 CC

DATE	TIME (HRS)	PRESS DROP (PSI)	TOTAL INJ (PV)	OIL PROD (CC)	WATER PROD (CC)	TOTAL OIL (% IOIP)	WOR	AVE. SAT.
2007	23.18	0.00	0.000	0.0	0.0	0.00	0.00	0.097
2107	3.38	15.10	0.092	59.1	0.1	7.54	0.00	0.189
2107	6.58	10.10	0.162	50.0	0.0	15.25	0.00	0.258
2107	10.00	6.20	0.228	55.3	1.0	23.77	0.01	0.324
2107	12.18	4.20	0.278	17.5	19.5	26.47	1.11	0.346
2107	15.05	3.60	0.337	8.1	36.7	27.72	4.53	0.354
2107	20.55	2.80	0.462	13.1	77.7	29.73	5.93	0.371
2207	10.39	2.20	0.699	18.0	158.5	32.51	8.80	0.387
2207	21.58	1.90	0.911	14.0	159.8	34.67	11.41	0.378
2307	12.55	1.60	1.255	32.2	223.2	39.63	6.93	0.411
2307	23.08	1.40	1.477	8.0	152.4	40.86	19.05	0.420
2407	12.08	1.30	1.755	8.9	200.1	42.23	22.48	0.420
2507	0.46	1.20	2.027	8.1	191.5	43.48	23.64	0.425
2507	8.30	1.15	2.330	3.5	116.9	44.02	33.40	0.566
2507	21.25	1.10	2.607	5.4	198.0	44.85	36.66	0.567
2607	11.30	1.00	2.863	4.5	181.9	45.55	40.42	0.570

TABLE D-10 (DISPLACEMENT DATA)

RUN-210
WAINWRIGHT(1080)CS

Q= 15.0 CC/HR   SWI= 8.31 PER CENT   K= 12.45 DARCY
TEMP= 22.2 C   KOI= 10.39 DARCY
IOIP= 682.9 CC   PORE VOL.= 744.8 CC

DATE	TIME (HRS)	PRESS DROP (PSI)	TOTAL INJ (PV)	OIL PROD (CC)	WATER PROD (CC)	TOTAL OIL (% IOIP)	WOR	AVE. SAT.
2807	11.15	0.00	0.000	0.0	0.0	0.00	0.00	0.083
2807	12.15	23.80	0.020	12.7	0.0	0.42	0.00	0.103
2807	14.14	15.30	0.060	25.3	0.0	4.12	0.00	0.143
2807	17.00	5.30	0.107	30.0	6.0	8.52	0.20	0.182
2807	20.00	5.20	0.176	19.0	36.6	11.30	1.92	0.202
2907	3.45	3.90	0.334	39.5	78.3	17.08	1.98	0.255
2907	10.55	3.60	0.469	21.4	94.4	20.22	4.41	0.263
2907	17.30	3.00	0.604	16.7	88.1	22.66	5.27	0.279
3007	1.45	2.80	0.771	19.3	104.7	25.49	5.42	0.307
3007	9.42	2.60	0.931	13.6	110.0	27.48	8.08	0.319
3007	17.45	2.20	1.099	14.1	112.4	29.55	7.97	0.336
3107	1.58	2.10	1.264	11.0	112.0	31.16	10.18	0.350
3107	14.00	2.00	1.491	14.4	161.7	33.26	11.22	0.360
3107	21.45	1.90	1.659	10.6	11.3	34.82	1.07	0.513
108	14.12	1.80	1.987	18.4	229.5	37.51	12.47	0.532
208	10.43	1.70	2.401	19.7	296.2	40.40	15.03	0.549
208	20.00	1.60	2.605	8.5	149.1	41.64	17.54	0.553
308	10.50	1.60	2.886	9.3	204.1	43.00	21.94	0.560
308	20.10	1.50	3.074	7.4	132.5	44.09	17.90	0.570

TABLE D-11 (DISPLACEMENT DATA)

RUN-211
WAINWRIGHT(1080)CS

Q= 25.0 CC/HR
TEMP= 22.2 C
IOIP= 679.8 CC

SWI= 9.68 PER CENT
KOI= 10.41 DARCY
PORE VOL.= 752.6 CC

K= 12.64 DARCY

DATE	TIME (HRS)	PRESS DROP (PSI)	TOTAL INJ (PV)	OIL PROD (CC)	WATER PROD (CC)	TOTAL OIL (%IOIP)	WOR	AVE. SAT.
3007	11.10	0.00	0.000	0.0	0.0	0.00	0.00	0.096
3007	11.49	38.20	0.022	11.5	0.0	0.25	0.00	0.119
3007	12.02	35.00	0.030	3.9	0.0	0.82	0.00	0.127
3007	14.13	10.40	0.108	52.1	3.0	8.48	0.05	0.201
3007	14.43	8.80	0.134	8.8	11.2	9.78	1.27	0.212
3007	21.41	5.20	0.372	40.5	146.3	15.73	3.61	0.255
3107	2.30	4.80	0.531	18.8	104.9	18.50	5.57	0.275
3107	7.30	4.50	0.697	15.0	112.4	20.71	7.49	0.292
3107	13.25	4.00	0.906	18.4	143.6	23.41	7.80	0.310
3107	21.00	3.70	1.166	22.2	181.1	26.68	8.15	0.330
108	13.58	3.00	1.687	42.8	407.7	32.98	9.52	0.309
108	20.14	2.80	1.950	16.4	152.0	35.39	9.26	0.370
208	10.38	2.60	2.444	31.2	354.1	39.98	11.34	0.394
208	21.33	2.20	2.810	25.7	267.8	43.76	10.42	0.403
308	10.50	2.10	3.264	14.0	339.6	45.82	24.25	0.406
308	20.10	2.00	3.582	11.3	237.4	47.48	21.00	0.409

TABLE D-12 (DISPLACEMENT DATA)

RUN-212
WAINWRIGHT(1080)CS

Q= 50.0 CC/HR　SWI= 9.93 PER CENT　K= 11.99 DARCY
TEMP= 22.2 C　KOI= 11.12 DARCY
IOIP= 678.9 CC　PORE VOL.= 753.7 CC

DATE	TIME (HRS)	PRESS DROP (PSI)	TOTAL INJ (PV)	OIL PROD (CC)	WATER PROD (CC)	TOTAL OIL (%IOIP)	WOR	AVE. SAT.
1108	13.43	0.00	0.000	0.0	0.0	0.00	0.00	0.099
1108	14.07	69.20	0.026	11.0	0.0	0.17	0.00	0.125
1108	14.28	59.90	0.049	18.1	0.0	2.84	0.00	0.148
1108	14.45	49.90	0.068	16.2	0.0	5.22	0.00	0.168
1108	15.15	34.50	0.100	27.9	0.0	9.33	0.00	0.200
1108	15.38	22.80	0.127	22.9	0.1	12.71	0.00	0.226
1108	16.21	15.40	0.173	18.4	21.1	15.42	1.14	0.244
1108	19.15	9.70	0.367	29.7	121.4	19.79	4.08	0.277
1108	23.34	8.30	0.652	26.6	195.5	23.71	7.34	0.303
1208	9.40	5.40	1.328	52.0	472.1	31.37	9.07	0.352
1208	13.13	5.00	1.553	10.9	159.5	32.97	14.63	0.366
1208	16.39	4.80	1.779	11.6	163.9	34.68	14.12	0.374
1208	23.22	4.60	2.224	21.3	289.5	37.82	13.59	0.436

TABLE D-13 (DISPLACEMENT DATA)

RUN-213
WAINWRIGHT(1080)CS

Q= 7.5 CC/HR   SWI= 9.28 PER CENT   K= 10.35 DARCY
TEMP= 21.6 C   KOI= 9.16 DARCY
IOIP= 653.3 CC   PORE VOL.= 720.3 CC

DATE	TIME (HRS)	PRESS DROP (PSI)	TOTAL INJ (PV)	OIL PROD (CC)	WATER PROD (CC)	TOTAL OIL (%IOIP)	WOR	AVE. SAT.
808	12.10	0.00	0.000	0.0	0.0	0.00	0.00	0.092
808	16.13	13.08	0.041	20.7	0.0	3.16	0.00	0.134
808	19.26	4.54	0.074	30.4	0.0	7.82	0.00	0.167
808	21.24	2.30	0.095	4.5	8.0	8.50	1.77	0.177
808	23.10	2.16	0.113	9.2	10.2	9.91	1.10	0.181
908	12.28	2.14	0.252	20.8	85.5	13.10	4.11	0.201
908	17.00	2.08	0.299	5.7	30.2	13.97	5.29	0.206
908	23.28	2.00	0.366	7.6	41.7	15.13	5.48	0.215
1008	11.00	2.11	0.487	19.2	73.9	18.07	3.84	0.233
1008	23.16	1.81	0.616	17.3	81.8	20.72	4.72	0.249
1108	13.25	1.74	0.762	17.5	95.8	23.40	5.47	0.262
1108	23.30	1.64	0.866	11.3	72.3	25.13	6.39	0.265
1208	9.30	1.64	0.964	12.0	69.1	26.96	5.75	0.268
1308	14.00	1.58	1.263	29.7	198.8	31.51	6.69	0.290
1308	21.55	1.56	1.349	7.4	57.3	32.64	7.74	0.297
1408	10.50	1.47	1.392	2.0	28.4	32.95	14.20	0.301
1408	16.55	1.37	1.453	7.5	42.5	34.10	5.66	0.303
1408	20.40	1.33	1.495	3.7	26.5	34.66	7.16	0.308

TABLE D-14 (DISPLACEMENT DATA)

RUN-214
WAINWRIGHT(1080)CS

Q= 800.0 CC/HR　SWI= 9.34 PER CENT　K= 8.56 DARCY
TEMP= 22.2 C　KOI= 6.06 DARCY
IOIP= 682.4 CC　PORE VOL.= 752.7 CC

DATE	TIME (HRS)	PRESS DROP (PSI)	TOTAL INJ (PV)	OIL PROD (CC)	WATER PROD (CC)	TOTAL OIL (%IOIP)	WOR	AVE. SAT.
1408	12.08	0.00	0.000	0.0	0.0	0.00	0.00	0.093
1408	12.16	1200.00	0.154	73.2	0.0	9.29	0.00	0.247
1408	12.21	1100.00	0.239	70.0	0.0	19.54	0.00	0.332
1408	12.30	950.00	0.398	139.6	0.0	40.00	0.00	0.491
1408	12.31	930.00	0.411	10.0	0.1	41.47	0.01	0.505
1408	12.42	535.00	0.631	43.6	135.2	47.86	3.10	0.544
1408	12.52	356.00	0.807	24.8	115.0	51.49	4.63	0.568
1408	13.14	295.00	1.208	25.3	283.0	55.20	11.18	0.593
1408	14.12	275.00	1.691	14.9	256.3	57.38	17.20	0.735
1408	14.33	255.00	1.935	18.5	277.0	60.09	14.97	0.612
1408	14.53	216.00	2.307	21.2	263.8	63.20	12.44	0.633
1408	15.12	194.00	2.649	11.2	252.5	64.84	22.54	0.639
1408	16.04	188.00	3.115	18.2	342.1	67.51	18.79	0.651
1408	16.25	172.00	3.488	4.9	288.7	68.22	58.91	0.641
1408	16.44	162.00	3.832	5.6	262.0	69.05	46.78	0.637
1408	16.51	158.00	3.974	3.4	110.6	69.54	32.52	0.632

TABLE D-15 (DISPLACEMENT DATA)

RUN-215
WAINWRIGHT(1080)CS

Q= 100.0 CC/HR SWI= 9.41 PER CENT K= 8.32 DARCY
TEMP= 23.8 C KOI= 6.40 DARCY
IOIP= 663.1 CC PORE VOL.= 732.0 CC

DATE	TIME (HRS)	PRESS DROP (PSI)	TOTAL INJ (PV)	OIL PROD (CC)	WATER PROD (CC)	TOTAL OIL (%IOIP)	WOR	AVE. SAT.
1807	11.05	0.00	0.000	0.0	0.0	0.00	0.00	0.094
1807	11.20	290.00	0.038	18.3	0.0	1.28	0.00	0.132
1807	11.31	266.00	0.065	22.5	0.0	4.67	0.00	0.159
1807	11.50	225.00	0.106	36.2	0.0	10.13	0.00	0.200
1807	12.11	173.00	0.158	41.6	0.0	16.40	0.00	0.252
1807	12.31	132.00	0.204	49.1	0.5	23.81	0.01	0.298
1807	12.55	90.00	0.275	24.5	12.5	27.50	0.51	0.352
1807	13.10	55.00	0.453	39.6	104.2	33.47	2.63	0.387
1807	15.36	40.00	0.636	20.4	122.6	36.55	6.00	0.403
1807	16.57	32.60	0.825	15.6	123.9	38.90	7.94	0.422
1807	20.20	25.60	1.297	28.0	329.0	43.13	11.75	0.445
1807	22.42	22.60	1.617	15.1	222.7	45.40	14.74	0.461
1907	0.02	21.20	1.806	10.0	131.7	46.91	13.17	0.470
1907	4.45	20.80	2.517	24.0	493.7	50.53	20.57	0.506
1907	9.52	20.20	3.168	21.0	485.7	53.70	23.12	0.494
1907	13.31	19.40	3.666	13.9	360.1	55.79	25.90	0.499
1907	16.35	18.40	4.095	11.4	313.6	57.51	27.50	0.501

TABLE D-16 (DISPLACEMENT DATA)

RUN-216
WAINWRIGHT(1080)CS

Q= 80.0 CC/HR SWI= 9.10 PER CENT K= 8.17 DARCY
TEMP= 21.1 C KOI= 7.02 DARCY
IOIP= 651.6 CC PORE VOL.= 716.9 CC

DATE	TIME (HRS)	PRESS DROP (PSI)	TOTAL INJ (PV)	OIL PROD (CC)	WATER PROD (CC)	TOTAL OIL (%IOIP)	WOR	AVE. SAT.
2208	14.34	0.00	0.000	0.0	0.0	0.00	0.00	0.091
2208	14.53	225.50	0.034	15.3	0.0	0.84	0.00	0.125
2208	15.23	176.00	0.097	49.9	0.0	8.50	0.00	0.188
2208	16.29	84.50	0.223	99.5	1.0	23.77	0.01	0.312
2208	17.09	57.20	0.298	34.4	25.6	29.05	0.74	0.352
2208	20.00	32.00	0.619	37.4	199.7	34.79	5.33	0.394
2208	22.54	24.40	0.945	21.3	217.9	38.06	10.23	0.417
2308	4.30	20.00	1.594	29.5	434.4	42.58	14.72	0.459
2308	9.58	17.00	2.215	18.0	430.9	45.34	23.93	0.479
2308	14.15	16.50	2.706	12.0	338.2	47.19	28.18	0.498
2308	22.00	14.00	3.587	23.6	603.8	50.81	25.58	0.538
2308	23.33	14.00	3.760	5.1	124.5	51.59	24.41	0.537

TABLE D-17 (DISPLACEMENT DATA)

RUN-217
WAINWRIGHT(1080)CS

Q= 200.0 CC/HR SWI= 7.30 PER CENT K= 9.42 DARCY
TEMP= 20.0 C KOI= 7.36 DARCY
IOIP= 692.3 CC PORE VOL.= 746.7 CC

DATE	TIME (HRS)	PRESS DROP (PSI)	TOTAL INJ (PV)	OIL PROD (CC)	WATER PROD (CC)	TOTAL OIL (%IOIP)	WOR	AVE. SAT.
2608	10.22	0.00	0.000	0.0	0.0	0.00	0.00	0.072
2608	10.33	583.00	0.050	23.2	0.0	1.93	0.00	0.123
2608	10.41	559.00	0.091	21.8	0.0	5.08	0.00	0.164
2608	10.50	523.00	0.128	22.0	0.0	8.26	0.00	0.201
2608	11.00	474.00	0.174	40.1	0.0	14.05	0.00	0.247
2608	11.14	424.00	0.238	52.5	0.0	21.63	0.00	0.311
2608	11.27	363.00	0.294	49.7	0.0	28.81	0.00	0.367
2608	11.40	269.00	0.334	31.5	0.7	33.37	0.02	0.406
2608	12.45	175.00	0.646	76.2	156.2	44.38	2.04	0.509
2608	14.00	90.00	0.991	21.5	223.8	47.48	10.40	0.554
2608	15.06	79.00	1.304	11.9	199.7	49.20	16.78	0.600
2608	16.48	64.00	1.744	13.0	322.7	51.08	24.82	0.608
2608	17.47	59.00	2.020	8.3	202.3	52.28	24.37	0.613
2608	19.11	55.00	2.395	8.1	274.6	53.45	33.90	0.620
2608	20.42	52.00	2.804	9.1	305.6	54.76	33.58	0.619
2608	22.01	50.00	3.164	5.4	274.9	55.54	50.90	0.611
2608	22.08	48.90	3.361	4.2	146.9	56.15	34.97	0.612

TABLE D-18 (DISPLACEMENT DATA)

RUN-218
WAINWRIGHT(1080)CS

Q= 400.0 CC/HR　SWI= 7.03 PER CENT　K= 9.66 DARCY
TEMP= 21.1 C　KOI= 9.22 DARCY
IOIP= 672.2 CC　PORE VOL.= 723.0 CC

DATE	TIME (HRS)	PRESS DROP (PSI)	TOTAL INJ (PV)	OIL PROD (CC)	WATER PROD (CC)	TOTAL OIL (%IOIP)	WOR	AVE. SAT.
2908	11.00	0.00	0.000	0.0	0.0	0.00	0.00	0.070
2908	11.09	943.00	0.078	34.9	0.0	3.73	0.00	0.149
2908	11.14	904.00	0.124	35.0	0.0	8.94	0.00	0.194
2908	11.23	714.00	0.215	70.5	0.0	19.42	0.00	0.286
2908	11.33	595.00	0.304	68.8	0.0	29.66	0.00	0.374
2908	11.34	575.00	0.315	9.3	0.1	31.04	0.01	0.385
2908	11.39	431.00	0.365	28.8	8.7	35.33	0.30	0.423
2908	12.00	333.00	0.558	50.8	89.4	42.88	1.75	0.493
2908	12.20	275.00	0.748	28.9	113.4	47.18	3.92	0.525
2908	12.41	230.00	0.947	15.7	131.8	49.52	8.39	0.542
2908	13.01	203.00	1.136	11.0	130.7	51.16	11.88	0.551
2908	13.21	182.00	1.322	7.9	127.4	52.33	16.12	0.560
2908	13.43	163.00	1.524	7.0	142.7	53.37	20.38	0.565
2908	14.04	147.00	1.723	5.8	141.9	54.23	24.46	0.568
2908	14.25	137.00	1.910	4.2	134.1	54.86	31.92	0.569
2908	14.48	127.00	2.135	5.2	156.3	55.63	30.05	0.578
2908	15.10	118.00	2.333	4.9	153.4	56.36	31.30	0.564
2908	15.33	111.00	2.562	2.6	157.3	56.75	60.50	0.576
2908	16.00	104.00	2.766	3.7	145.3	57.30	39.27	0.578
2908	16.21	99.00	3.020	3.3	157.1	57.79	47.60	0.615
2908	16.45	96.00	3.236	3.3	156.2	58.28	47.33	0.615
2908	17.48	92.00	3.461	2.3	168.8	58.62	73.39	0.606

TABLE D-19 (DISPLACEMENT DATA)

RUN-219
WAINWRIGHT(1080)CS

Q= 600.0 CC/HR SWI= 7.13 PER CENT K= 11.43 DARCY
TEMP= 22.2 C KOI= 8.03 DARCY
IOIP= 692.1 CC PORE VOL.= 745.2 CC

DATE	TIME (HRS)	PRESS DROP (PSI)	TOTAL INJ (PV)	OIL PROD (CC)	WATER PROD (CC)	TOTAL OIL (%IOIP)	WOR	AVE. SAT.
909	8.15	0.00	0.000	0.0	0.0	0.00	0.00	0.071
909	8.23	1250.00	0.080	30.8	0.0	3.03	0.00	0.151
909	8.26	1340.00	0.123	30.8	0.0	7.48	0.00	0.194
909	8.29	1230.00	0.161	30.8	0.0	11.93	0.00	0.232
909	8.32	940.00	0.201	29.7	0.1	16.22	0.00	0.272
909	8.35	505.00	0.249	31.9	12.9	20.83	0.40	0.303
909	8.41	375.00	0.328	24.7	40.4	24.40	1.63	0.328
909	8.47	307.00	0.409	18.0	43.9	27.00	2.43	0.349
909	8.56	225.00	0.536	32.3	66.5	31.67	2.05	0.388
909	9.06	165.00	0.670	17.0	83.5	34.12	4.91	0.410
909	9.16	122.00	0.805	12.1	94.9	35.87	7.84	0.417
909	9.25	102.00	0.925	9.5	88.5	37.24	9.31	0.419
909	9.41	90.00	1.153	8.6	162.7	38.49	18.91	0.429
909	10.01	85.00	1.356	7.4	151.3	39.56	20.44	0.428
909	10.15	81.00	1.552	4.6	144.1	40.22	31.32	0.431
909	10.31	77.00	1.759	5.3	153.7	40.99	29.00	0.431
909	10.46	74.00	1.973	4.0	156.8	41.56	39.20	0.435
909	11.02	72.00	2.193	8.6	162.7	42.81	18.91	0.437
909	11.17	69.00	2.405	3.3	160.4	43.28	48.60	0.434
909	11.33	67.00	2.625	3.2	165.9	43.75	51.84	0.431
909	11.54	65.00	2.847	2.4	164.3	44.09	68.45	0.432
909	12.10	62.00	3.086	1.3	177.9	44.28	136.84	0.432
909	12.27	60.00	3.314	1.2	169.4	44.45	141.16	0.433
909	12.41	59.00	3.515	1.5	148.1	44.67	98.73	0.436

TABLE D-20 (DISPLACEMENT DATA)

RUN-220
WAINWRIGHT(1080)CS

Q= 800.0 CC/HR   SWI= 7.18 PER CENT   K= 12.52 DARCY
TEMP= 20.5 C   KOI= 9.36 DARCY
IOIP= 711.2 CC   PORE VOL.= 766.2 CC

DATE	TIME (HRS)	PRESS DROP (PSI)	TOTAL INJ (PV)	OIL PROD (CC)	WATER PROD (CC)	TOTAL OIL (%IOIP)	WOR	AVE. SAT.
1909	8.25	0.00	0.000	0.0	0.0	0.00	0.00	0.071
1909	8.30	1620.00	0.079	30.4	0.0	2.89	0.00	0.151
1909	8.32	1800.00	0.125	30.2	0.0	7.14	0.00	0.197
1909	8.35	1750.00	0.164	30.7	0.0	11.45	0.00	0.236
1909	8.37	1600.00	0.198	30.4	0.0	15.73	0.00	0.270
1909	8.39	1425.00	0.234	31.0	0.0	20.09	0.00	0.306
1909	8.40	1310.00	0.255	19.5	0.0	22.83	0.00	0.327
1909	8.42	880.00	0.284	28.0	1.5	26.77	0.05	0.354
1909	8.44	510.00	0.336	30.8	1.5	31.10	0.04	0.404
1909	8.47	475.00	0.378	22.7	12.5	34.29	0.55	0.430
1909	8.49	407.00	0.422	15.7	21.0	36.50	1.33	0.447
1909	9.01	255.00	0.626	23.5	138.5	39.80	5.89	0.469
1909	9.14	160.00	0.866	27.2	160.5	43.63	5.90	0.500
1909	9.28	125.00	1.119	9.7	174.0	44.99	17.93	0.526
1909	9.38	122.00	1.297	4.5	138.5	45.62	30.77	0.523
1909	10.33	120.00	1.527	8.0	168.0	46.75	21.00	0.533
1909	10.45	113.00	1.735	4.4	158.6	47.37	36.04	0.535
1909	10.56	107.00	1.934	3.0	153.9	47.79	51.30	0.533
1909	11.08	103.00	2.140	3.2	157.6	48.24	49.25	0.533
1909	11.20	98.00	2.357	2.9	165.3	48.65	57.00	0.534
1909	11.32	95.00	2.560	2.0	154.0	48.93	77.00	0.537

TABLE D-21 (DISPLACEMENT DATA)

RUN-221
WAINWRIGHT(1080)CS

Q= 800.0 CC/HR SWI= 5.40 PER CENT K= 15.09 DARCY
TEMP= 21.1 C KOI= 13.24 DARCY
IOIP= 741.3 CC PORE VOL.= 794.6 CC

DATE	TIME (HRS)	PRESS DROP (PSI)	TOTAL INJ (PV)	OIL PROD (CC)	WATER PROD (CC)	TOTAL OIL (%IOIP)	WOR	AVE. SAT.
1709	10.40	0.00	0.000	0.0	0.0	0.00	0.00	0.054
1709	10.44	1307.00	0.075	35.3	0.0	3.38	0.00	0.129
1709	10.47	1340.00	0.113	30.2	0.0	7.45	0.00	0.167
1709	10.49	1245.00	0.151	31.7	0.0	11.73	0.00	0.205
1709	10.51	1110.00	0.188	31.6	0.0	15.99	0.00	0.242
1709	10.55	827.00	0.259	63.8	0.0	24.60	0.00	0.313
1709	11.00	510.00	0.337	64.7	0.3	33.33	0.00	0.390
1709	11.03	350.00	0.382	14.1	22.5	35.23	1.59	0.407
1709	11.10	284.00	0.503	24.8	77.2	38.58	3.11	0.431
1709	11.20	188.00	0.692	18.8	133.4	41.11	7.09	0.452
1709	11.30	150.00	0.843	7.7	112.4	42.15	14.59	0.461
1709	11.40	125.00	1.016	3.8	142.0	42.66	37.36	0.456
1709	11.50	108.00	1.220	4.7	159.9	43.30	34.02	0.459
1709	12.04	105.00	1.430	3.8	166.6	43.81	43.84	0.460
1709	12.15	97.00	1.619	2.9	155.0	44.20	53.44	0.453
1709	12.26	93.00	1.820	2.1	158.5	44.48	75.47	0.455
1709	12.39	88.00	2.029	2.0	163.5	44.75	81.75	0.458

TABLE D-22 (DISPLACEMENT DATA)

RUN-401
DC200(500)CS

Q= 10.0 CC/HR　SWI=10.20 PER CENT　K= 16.46 DARCY
TEMP= 22.0 C　KOI= 15.00 DARCY
IOIP=2666.9 CC　PORE VOL.=2969.5 CC

DATE	TIME (HRS)	PRESS DROP (PSI)	TOTAL INJ (PV)	OIL PROD (CC)	WATER PROD (CC)	TOTAL OIL (%IOIP)	WOR	AVE. SAT.
501	16.45	0.00	0.000	0.0	0.0	0.00	0.00	0.102
501	19.55	2.11	0.010	28.5	0.0	0.07	0.00	0.112
601	10.40	1.36	0.062	152.7	0.0	5.80	0.00	0.164
601	14.25	1.24	0.074	40.0	0.0	7.30	0.00	0.176
601	22.10	1.04	0.101	81.4	0.0	10.35	0.00	0.203
701	13.25	0.99	0.153	152.5	0.8	16.07	0.00	0.255
701	14.50	0.98	0.158	14.1	7.9	16.60	0.56	0.258
701	20.00	0.90	0.176	28.9	22.9	17.68	0.79	0.268
701	22.00	0.90	0.183	13.5	9.0	18.19	0.66	0.271
801	11.30	0.76	0.230	71.0	72.2	20.85	1.01	0.294
801	21.05	0.65	0.249	19.7	39.1	21.59	1.98	0.300
901	9.30	0.61	0.292	39.7	92.3	23.08	2.32	0.312
901	19.55	0.56	0.328	25.3	81.3	24.02	3.21	0.320
1001	23.50	0.47	0.424	53.3	241.6	26.02	4.53	0.336
1101	10.10	0.45	0.460	18.1	92.8	26.70	5.12	0.340
1201	10.00	0.41	0.530	27.3	187.3	27.73	6.86	0.347
1201	20.00	0.40	0.564	12.3	91.0	28.19	7.39	0.350
1401	8.50	0.41	0.643	27.0	214.0	29.20	7.92	0.357
1401	21.15	0.39	0.686	10.9	120.5	29.61	11.05	0.360
1501	10.10	0.40	0.731	12.2	125.1	30.07	10.25	0.362
1501	21.00	0.39	0.770	8.6	107.7	30.39	12.52	0.365
1601	10.40	0.38	0.817	7.9	130.1	30.68	16.46	0.368
1601	23.20	0.38	0.861	7.9	125.6	30.98	15.89	0.369
1701	21.30	0.38	0.937	12.7	215.5	31.46	16.96	0.373
1801	15.00	0.38	0.984	9.0	129.0	31.79	14.33	0.377
1901	11.00	0.39	1.062	7.8	197.0	32.09	25.25	0.389
2001	9.20	0.35	1.136	12.3	209.2	32.55	17.00	0.392
2001	19.00	0.33	1.169	4.8	97.2	32.73	20.25	0.392
2101	19.00	0.35	1.250	10.5	231.0	33.12	22.00	0.396
2201	17.30	0.35	1.328	9.0	219.0	33.46	24.33	0.400
2401	16.00	0.35	1.480	13.0	439.0	33.95	33.76	0.404
2501	16.00	0.34	1.563	7.0	236.0	34.21	33.71	0.408
2601	15.30	0.34	1.644	7.5	228.0	34.49	30.40	0.412
2701	16.35	0.33	1.731	8.0	250.0	34.79	31.25	0.415

TABLE D-23 (DISPLACEMENT DATA)

RUN-402
DC200(500)CS

Q= 40.0 CC/HR　　SWI=10.80 PER CENT　　K= 18.28 DARCY
TEMP= 22.0 C　　KOI= 15.73 DARCY
IOIP=2631.6 CC　　PORE VOL.=2961.4 CC

DATE	TIME (HRS)	PRESS DROP (PSI)	TOTAL INJ (PV)	OIL PROD (CC)	WATER PROD (CC)	TOTAL OIL (% IOIP)	WOR	AVE. SAT.
1305	15.50	0.00	0.000	0.0	0.0	0.00	0.00	0.108
1305	16.50	7.65	0.013	37.0	0.0	0.09	0.00	0.121
1305	19.30	6.45	0.050	108.0	0.0	4.19	0.00	0.158
1305	20.50	6.11	0.069	50.0	0.0	6.09	0.00	0.177
1305	21.45	5.86	0.081	36.5	0.0	7.48	0.00	0.189
1405	11.00	1.62	0.237	464.0	0.0	25.11	0.00	0.345
1405	12.00	1.56	0.249	18.7	15.9	25.82	0.85	0.352
1405	16.30	1.29	0.312	45.7	141.0	27.56	3.08	0.367
1405	23.20	1.10	0.393	34.5	206.0	28.87	5.97	0.379
1505	11.30	0.83	0.569	57.0	467.2	31.04	8.19	0.397
1505	16.15	0.75	0.636	17.6	180.5	31.71	10.25	0.403
1505	22.00	0.71	0.716	18.5	218.5	32.41	11.81	0.409
1605	10.30	0.65	0.884	30.0	465.2	33.55	15.50	0.420
1605	16.00	0.62	0.962	9.5	220.5	33.91	23.21	0.423
1605	21.00	0.51	1.029	8.0	191.0	34.21	23.87	0.426
1705	9.25	0.49	1.197	21.6	478.6	35.03	22.15	0.432
1705	15.30	0.46	1.280	12.0	235.0	35.49	19.58	0.436
1705	21.30	0.41	1.364	7.5	238.0	35.77	31.73	0.440
1805	10.00	0.40	1.532	13.8	481.9	36.30	34.92	0.445
1805	15.50	0.38	1.613	8.5	231.0	36.62	27.17	0.448
1805	20.30	0.37	1.678	3.2	190.0	36.74	59.37	0.449
1905	8.45	0.37	1.846	13.7	486.7	37.26	35.52	0.453
1905	15.30	0.36	1.938	8.0	263.0	37.57	32.87	0.455
1905	21.15	0.34	2.014	9.0	221.0	37.91	24.55	0.457
2005	9.30	0.34	2.178	11.4	471.9	38.34	41.39	0.462
2005	15.30	0.34	2.260	4.0	244.0	38.50	61.00	0.461
2005	21.30	0.33	2.341	3.0	23.6	38.61	7.88	0.535
2105	9.30	0.31	2.509	11.0	480.0	39.03	43.63	0.540
2105	15.00	0.31	2.583	5.5	215.5	39.24	39.18	0.542
2105	21.30	0.31	2.676	60.0	263.0	41.52	4.38	0.545
2205	9.00	0.31	2.845	12.5	489.5	41.99	39.16	0.549

TABLE D-24 (DISPLACEMENT DATA)

RUN-403
DC200(500)CS

Q= 600.0 CC/HR SWI=11.73 PER CENT K= 11.33 DARCY
TEMP= 21.0 C KOI= 10.09 DARCY
IOIP=2654.8 CC PORE VOL.=3007.5 CC

DATE	TIME (HRS)	PRESS DROP (PSI)	TOTAL INJ (PV)	OIL PROD (CC)	WATER PROD (CC)	TOTAL OIL (%IOIP)	WOR	AVE. SAT.
1906	14.40	0.00	0.000	0.0	0.0	0.00	0.00	0.117
1906	14.44	164.20	0.014	42.5	0.5	0.30	0.01	0.131
1906	14.50	153.40	0.033	54.9	0.5	2.36	0.00	0.150
1906	15.00	134.30	0.068	94.0	0.7	5.90	0.00	0.185
1906	15.10	112.30	0.103	99.1	0.6	9.64	0.00	0.219
1906	15.20	86.00	0.135	97.0	0.7	13.29	0.00	0.251
1906	15.25	75.00	0.149	42.0	1.0	14.87	0.02	0.265
1906	15.36	54.60	0.190	81.9	35.1	17.96	0.42	0.294
1906	15.53	40.80	0.250	86.1	96.8	21.20	1.12	0.322
1906	16.12	32.40	0.309	59.4	123.4	23.44	2.07	0.340
1906	16.34	29.80	0.371	44.8	142.0	25.13	3.16	0.355
1906	16.52	24.00	0.434	37.8	157.0	26.55	4.15	0.366
1906	17.12	21.00	0.498	32.7	159.8	27.78	4.88	0.377
1906	17.35	18.40	0.581	30.0	218.0	28.91	7.26	0.387
1906	17.53	16.90	0.641	22.4	161.5	29.76	7.20	0.393
1906	18.36	14.60	0.770	39.0	352.0	31.22	9.02	0.405
1906	19.12	13.00	0.897	33.2	348.4	32.48	10.49	0.416
1906	19.53	11.60	1.021	38.5	345.1	33.93	8.96	0.426
1906	20.11	11.40	1.082	10.0	172.5	34.30	17.25	0.429
1906	20.29	11.00	1.140	11.2	173.8	34.72	15.51	0.430
1906	20.47	10.40	1.204	10.5	174.6	35.12	16.62	0.436
1906	21.24	9.70	1.326	20.5	356.7	35.89	17.39	0.439
1906	21.49	9.30	1.393	10.0	188.5	36.27	18.85	0.443
1906	22.31	8.90	1.536	17.8	413.2	36.94	23.21	0.448
1906	22.49	8.60	1.596	6.4	177.9	37.18	27.79	0.450
1906	23.31	8.00	1.721	17.4	357.0	37.84	20.51	0.456
1906	23.50	8.00	1.785	6.8	187.8	38.09	27.61	0.457
2006	0.27	7.60	1.910	13.2	364.6	38.59	27.62	0.461
2006	0.50	7.50	1.989	7.0	237.9	38.85	33.98	0.461
2006	2.11	7.00	2.117	13.7	365.0	39.37	26.64	0.468
2006	2.30	6.80	2.182	5.3	191.7	39.57	36.16	0.469
2006	3.18	6.50	2.327	13.4	421.7	40.07	31.47	0.474
2006	3.55	6.40	2.451	10.7	367.5	40.48	34.34	0.476
2006	4.29	6.20	2.576	7.5	367.8	40.76	49.04	0.478
2006	5.15	5.90	2.716	11.6	416.6	41.20	35.91	0.480
2006	5.58	5.80	2.845	11.2	376.3	41.62	33.59	0.484

TABLE D-25 (DISPLACEMENT DATA)

RUN-404
DC200(500)CS

Q=1120.0 CC/HR SWI=10.34 PER CENT K= 10.39 DARCY
TEMP= 22.0 C KOI= 9.89 DARCY
IOIP=2589.9 CC PORE VOL.=2888.6 CC

DATE	TIME (HRS)	PRESS DROP (PSI)	TOTAL INJ (PV)	OIL PROD (CC)	WATER PROD (CC)	TOTAL OIL (%IOIP)	WOR	AVE. SAT.
2507	2.11	0.00	0.000	0.0	0.0	0.00	0.00	0.103
2507	2.22	298.00	0.055	135.2	0.5	3.88	0.00	0.158
2507	2.25	277.00	0.075	49.6	0.6	5.80	0.01	0.178
2507	2.37	156.00	0.155	231.9	2.3	14.75	0.01	0.257
2507	2.47	103.00	0.215	116.6	70.5	19.26	0.60	0.293
2507	2.58	80.80	0.281	72.8	118.8	22.07	1.63	0.318
2507	3.11	65.00	0.347	55.0	147.0	24.19	2.67	0.333
2507	3.32	47.60	0.478	86.1	290.5	27.52	3.37	0.363
2507	3.52	35.50	0.609	57.0	324.0	29.72	5.68	0.382
2507	4.06	31.00	0.694	30.0	227.8	30.87	7.59	0.389
2507	5.05	26.70	0.824	33.3	342.4	32.16	10.28	0.400
2507	5.25	24.60	0.949	30.6	339.5	33.34	11.09	0.407
2507	5.39	22.60	1.042	18.9	262.5	34.07	13.88	0.409
2507	6.27	20.80	1.139	21.0	349.3	34.88	16.63	0.385
2507	6.47	19.60	1.268	19.0	360.3	35.62	18.96	0.389
2507	7.00	18.60	1.355	13.7	264.5	36.15	19.30	0.385
2507	7.25	17.60	1.482	20.7	347.6	36.94	16.79	0.392
2507	7.46	16.40	1.612	13.8	375.2	37.48	27.18	0.392
2507	8.00	15.80	1.703	7.0	265.5	37.75	37.92	0.390